Investigation of Cesspool Upgrade Alternatives in Upcountry Maui

Final Report

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Executive Summary

Background and Project Aims

In Hawaiʻi, sewage has been identified as a major management challenge. Acknowledging the high risk associated with poor sewage management, recent legislation banned new cesspools across Hawaiʻi, but legacy cesspools remain and are polluting groundwater and the nearshore environment. Some areas in the State are at particularly high risk to the negative impacts of poor sewage management. The 12,000 homes and community facilities serving an area population of almost 31,000 people on the west facing slope of Haleakala Volcano, Maui, USA, referred to as Upcountry Maui, rely on 10,040 onsite sewage disposal system (OSDS) for domestic wastewater disposal. Of these, more than 7,400 are cesspools that release an estimated 4.4 million gallons per day of untreated wastewater containing 697 kg of nitrogen to the shallow subsurface. Nitrate concentrations of nearly 9 milligrams per liter (mg/L) have been measured in the groundwater water of Upcountry Maui, prompting the State Department of Health (DoH) to designate Upcountry Maui as a Priority 1 Cesspool Upgrade Area. This designation implies that cesspools in this area present a "significant risk of human impacts, drinking water impacts, or draining to sensitive waters", and are highest priority for action. A comprehensive analysis of upgrade alternatives is needed to inform a cost-effective strategy.

The aim of this research is to use evidence to help design nutrient pollution solutions that will reduce the most pollution at a reasonable cost, while considering equity. We employ a structured decision-making approach to determine how alternative management practices may influence groundwater nitrogen levels and at what cost; and where nutrient reductions would be most beneficial to meet both water quality regulations/objectives, and other social goals. Specifically, we 1) identify a range of cesspool replacement options, 2) develop a range of management alternatives that incorporate technical feasibility, 3) analyze environmental benefit of each alternative; 4) enumerate costs of the alternatives; and 5) provide recommendations on the alternatives relative to cost, environmental benefit, and stakeholder-identified objectives.

Approach

The structured decision-making process involved seven steps, consistent with a decision-theoretic process:

1) Define the problem – In brief, based on its mandate to protect drinking water, the Department of Health is empowered to recommend action to the State legislature to address pollutant levels in the groundwater that are nearing safe drinking water standards. In the case of Upcountry Maui, cesspools are a major current contributor of nitrogen flux into the groundwater.

2) Define objectives and select metrics – A stakeholder working group that included community members and government officials identified twelve objectives and metrics spanning cost, nitrogen reductions, equity in cost sharing, and feasibility that they want to achieve.

3) Identify, cost, and map feasible options (and constraints) – Various cesspool conversion options exist, from on-site systems that better reduce nitrogen than cesspools to alternative technologies to sewering. We specified the capital investment and operation and maintenance costs for each option, as well as their conditions and constraints (e.g., site characteristics).

4) Screen options – For each of the OSDS units in our study area, we assessed the feasibility of each of the upgrade options considered, using geospatial data corresponding to the constraints.

5) Develop alternatives – During exercises designed specifically to elicit creative thinking, participants of stakeholder discussions and a workshop developed alternative packages of options to upgrade cesspools. The project team used these inputs to design 41 alternatives to define, map, and evaluate.

6) Estimate consequences (accounting for local preferences and values) – Alternatives were evaluated using an existing groundwater flow and transport model that predicted how the various packages of upgrade options would perform when deployed across the landscape. The net present value of all capital and operation and maintenance costs were assessed for each alternative. A modified cost-benefit analysis assessed the nitrogen flux reduction per dollar cost. Equity was assessed by calculating the variability in cost burden across the households with cesspools and by comparing the costs borne by these households to the sewage fees paid by other Maui homes connected to county sewer systems. Other social objectives, such as design standards and maintenance burden, were evaluated using expert opinion.

7) Consider trade-offs – The final step evaluated how the various alternatives fared for each of the 10 objectives and considered the trade-offs. All alternatives were compared to each other, and to the “do nothing” (i.e., status quo) option. The results of this analysis are summarized below.

Results

Status quo. Under current conditions, the groundwater model predicted a maximum concentration of dissolved inorganic nitrogen of over 10 mg/l in one part of the project area (990 acres) and over 5 mg/L in a larger part (nearly 9,000 acres). Cesspools were estimated to be the second largest contributor (24%) of nitrogen flux to the groundwater after historical sugar cane production (55%).

Alternatives.

A strategy evaluation table is designed to serve as a decision aid. The table can be used to evaluate individual alternatives, or compare across alternatives. The first cut are alternatives that perform poorly across multiple objectives, and should thus not be considered – such as well-head treatment, which fails to decrease groundwater risk, and consequently also has zero cost-effectiveness.

The strategy evaluation table (reveals an obvious winner, composting toilets, which meets the fundamental objectives of reducing cost, impact, and risk, while ensuring equity, but it does not meet the cesspool ban nor comply with current regulations. There are also significant technical and social hurdles to overcome, which we did not address in this analysis. A number of septic tank alternatives (Alt 6, 8, 10, 19A) perform well across multiple objectives, as do the sewering Makawao (or Pukalani) combined with septic tank to Presby where possible alternatives (Alt 20-22, 23B-25B). The key difference between these alternatives is the risk of exceeding 5 and 10mg/l nitrate standards, which is quite a bit higher in the former. Alternatives that only sewer the neighborhoods without attending to the cesspools at all are the cheapest alternatives, both overall and per household, but they result in potentially unacceptable risk to aquifers and low flux reduction benefits.

If decision makers cannot allow any area to reach >10mg/l, then many alternatives are eliminated. The lowest cost alternative to meet the 10mg/l standard will cost $227 million over the 60-year project timeframe. Relatively low-cost septic tank-based alternatives (8, 10) meet this standard, at a much cheaper cost per household than the sewering alternatives (Alt 20-25), which have similar overall costs.

Alternatives that target the TMKs with the highest nitrogen contributions (Alt 19A and 19B) would cost $116 and $250 million, but the additional cost for 19B does not buy much result. 19B is far less cost-effective than 19A. Both these alternatives reduce the area at risk of over 10mg/L to about 100 acres, and only affect ~15% of households

Recommendations

This study represents the best available science on how different options for upgrading cesspools in Upcountry Maui would achieve stakeholder objectives. The research took a structured decision making approach, engaging a large working group of stakeholders in a participatory process to identify and assess how these options performed across an array of objectives using data and state-of-the-art modeling. Decision-makers can now use the analysis to choose their preferred options based on how well they perform against the objectives. It is up to the policy maker to weigh the various objectives. For instance, decision-makers concerned solely with minimizing nitrogen flux (protection of aquifer for drinking water) should choose Alternatives 20-25 or composting toilets, while those concerned with the lowest cost per household while meeting cesspool ban should focus on alternatives 10, 4B and 1. The following abbreviated recommendations are provided (longer descriptions are presented at the end of this report):

1. General

   a. Aquifers that are designated as potable should be maintained in that state and preserved for current and future use to the extent that is feasible via source control. In the case of Upcountry Maui, the only feasibly controllable source is OSDSs, which constitute approximately one third of the total nitrogen inputs which includes cesspools (24%). Cesspool upgrade alternatives that preserve the groundwater for potable use (nitrate-N <10 mg/L for 100% of the land area) include Alternatives 3, 4, 7, 8, 10-18, 20-25, and composting toilets.
2. Further Investigations
   a. Investigate inputs of chloramine into drinking water and thus emissions via cesspools, and, if appropriate, incorporate it into the groundwater model.
   b. Conduct a study on small cluster systems which could have cost efficiencies but require a detailed study than we were not able to provide.
   c. Investigate the cost of centralized sewering of the entire Upcountry community including a WWTP and a disposal system.
   d. Conduct a pilot study and then develop design standards for passive denitrifying absorption systems (Alts 9, 10, 17, 18) as well as Nitrex and Eliminite and Presby (with De-nyte) systems for the same purpose.
   e. Extend the study of Alts 19A/B to determine how many more TMKs would have to be included (in addition to the worst 20%) to achieve zero acres of >10mg/L nitrate.
   f. Conduct composting toilet study, to gain familiarity, experience maintenance issues, determine pathogen risks in compost, acceptable handling practices, and develop regulatory standards including permitting and maintenance requirements.
   g. Investigate financing options for completing any alternative program of upgrades, including: individual homeowner pays, state/federal grants, state tax credits, privatization of individual systems , County owning/operating all individual systems, and other options.
3. Program Management and Efficiency
   a. Conduct a study to determine a program management framework and the required DOH staffing to regulate all the OSDSs including the 88,000 upgraded cesspools in order to ensure public health is protected in the state.
   b. Develop design standards for drip irrigation systems, ET systems passive denitrifying absorption systems, to make approval of such systems routine instead of one-off design for each property as is the current situation.
   c. Develop regulations for operation and maintenance of composting toilets

4. Legislation and Administrative Actions
    a. Based on the investigations recommended above, write legislation to facilitate gray water, composting toilets, drip irrigation, ET systems, passive denitrifying absorption systems, program management including issuing OSDS permits and associated requirements, and financing methods.
    b. Criteria are needed to guide homeowner choices to ensure that sufficient nitrogen is removed, such that cumulatively all groundwater is maintained with <10mg/l of nitrate. We therefore strongly recommend that DOH develop such criteria.

The cesspool ban has regulatory efficiency, however, a systems perspective would improve outcomes, i.e., when the fundamental objective can be met by intervening in part of the system, these areas are targeted and exemptions to the ban might be considered for remaining households. Any system-scale solution would, of course, require subsidizing homeowners who upgrade. We recommend that DOH adopt a systems perspective, and design collective solutions and creative funding mechanisms to improve the economic efficiency. The project team would like to acknowledge the diligent and valuable inputs from the stakeholder working group participants. It is important to flag that they contributed to the process in good faith, despite fundamental disagreement with some of the key underlying premises of the project. This project started from the fact that Upcountry Maui is a Priority 1 area, and its aims were to identify the most cost-effective actions to upgrade cesspools in the area. Many of the stakeholders strongly disagreed with the prioritization of Upcountry for a number of reasons. They argued that that nitrogen flux from cesspools is a minor contributor compared to other sources; nitrogen from cesspools doesn't reach the groundwater; nitrogen loads in the groundwater are below drinking water standards nearly everywhere; evidence of contamination is limited to a handful of samples in a discrete area; no Upcountry residents get their water from the aquifer so drinking water standards aren't applicable; the only users of the aquifer for drinking water are private for-profit developers who choose not to wait for municipal water supply; and there is no documented evidence of human health/stream/coastal impacts. The project team were able to use empirical evidence and modeling to discuss some of these arguments, but the issue of prioritization remains a thorny one that is outside the scope of this analysis.

Table of Contents

Background

In Hawaiʻi, sewage has been identified as a major management challenge. Acknowledging the high risk associated with poor sewage management, new cesspools have been banned across Hawaiʻi, but legacy cesspools remain and are polluting groundwater and the nearshore environment (Whittier and El-Kadi 2009). In 2017, the Hawaii State Legislature passed Act 125 "Relating to Cesspools". This Act accomplished three things. First, it mandated that all cesspools in the State be either upgraded or converted by 2050, unless granted an exception for a legitimate reason, which include small lot sizes, steep topography, poor soils, and accessibility issues. Second, the Act expanded the criteria for an existing $10,000 tax credit to any citizen with a cesspool within 500 meters of a perennial stream, shoreline, or wetland; within an area designated as a source of drinking water; affecting drinking water supplies or recreational waters; or appropriate for connection to an existing sewerage system. Third, Act 125 requires the state Department of Health (DoH) to "investigate the number, scope, location, and priority of cesspools statewide that require upgrade, conversion, or connection based on each cesspool's impact on public health…and recommend any proposed legislation and administrative action". In parallel, DoH was mandated to assess the feasibility of a grant program to help property owners comply.

Some areas in the State are at particularly high risk to the negative impacts of poor sewage management. In 2017, DoH published its report prioritizing areas across the Main Hawaiian Islands, based on actual or potential impacts from cesspools to human health, drinking water, and sensitive waters. Due to the density of cesspools in the area and elevated groundwater nitrate concentrations, Upcountry Maui has been designated a Priority 1 Cesspool Upgrade Area (DOH, 2017). The 12,000 homes and community facilities on the west facing slope of Haleakala Volcano, Maui, USA, referred to as Upcountry Maui, rely on 10,040 onsite sewage disposal system (OSDS) for domestic wastewater disposal (DOH, 2018). Of these, more than 7,400 are cesspools that release untreated wastewater to the shallow subsurface. Nitrate concentrations of nearly 9 milligrams per liter (mg/L) have been measured in the groundwater water of Upcountry Maui (DOH, 2017). The USEPA health-based Maximum Contaminant Level (MCL) for nitrate is 10 mg/L. A Hawaii Department of Health investigation into the sources of the elevated groundwater nitrate concluded that, while not the only source, OSDS, primarily cesspools, significantly increased the groundwater nitrate concentration in the groundwater of Upcountry Maui. That study further estimated that the nitrate concentrations downgradient of the areas with the highest OSDS densities likely exceed the MCL of 10 mg/L (DOH, 2017 and 2018). Assuming 7,400 cesspools in Upcountry Maui required replacement at costs ranging from $20,000 to $60,000 each, the total cost of cesspool replacement could range from $120 million to $360 million. In addition, there will be on-going operation/maintenance costs as well as the need for a funded, effective management program. This is an onerous cost burden on the residents of Upcountry Maui and a comprehensive analysis of upgrade alternatives and a cost/benefit analysis is needed.

While the DOH report fulfilled the mandate in Act 125 to identify priority areas, it acknowledged the need for further analysis and continued stakeholder collaboration regarding the problems and solutions in the report in order to “eliminat[e] cesspools in an economically feasible way”. The aim of this research is to use evidence to help design nutrient pollution solutions that will reduce the most pollution at the least cost, while considering equity. We seek to identify and compare options including various types of cesspool upgrades and installation of sewers. To achieve the largest pollution reduction possible at the lowest cost, decision-makers require appropriate analytical tools to determine (i) how alternative management practices may influence groundwater nitrogen levels and at what cost; and (ii) where nutrient reductions would be most beneficial to meet both water quality regulations/objectives, and other social goals.

While this “best bang for your buck” mindset may seem simple, management of water quality in Hawaiʻi is characterized by complicated decisions under conditions of high uncertainty and risk. Managers frequently have to choose among complex and often competing environmental, social, and economic objectives – and effects of management are often uncertain (Liu et al. 2012). Consequently, managers often rely on *ad hoc* decision making, which ultimately falls short of achieving desired outcomes. A more structured approach, informed by decision science, can increase conservation impact, reduce costs, and increase cooperation across management agencies.

Structured decision making (SDM) is a collaborative process for decision-making that combines analytical methods from ecology and decision science with facilitation/negotiation and social psychology to develop rigorous, inclusive, and transparent decisions that balance multiple stakeholder objectives. It has been applied to resolve a spectrum of wicked environmental management problems. SDM draws on decision analysis (DA) – a discipline with a deep theory and body of practice (Howard 1988; Pratt et al. 1995; Skinner et al. 2011) that uses established methods and tools to formally dissect key aspects of complex decisions in order to recommend actions that lead to outcomes that ultimately maximize expected utility (Keeney 1996).

Decision analysis tools can lead to better outcomes for nature and people, stronger community support for actions, and more cost efficient and impactful choices (White et al. 2012). It is particularly well suited to finding solutions to problems where there are many unknowns, or where risks may be high, as in the case of Hawaii’s cesspools. In the face of high levels of uncertainty in cost, benefit, feasibility, and effectiveness of management options, under accelerating future change, decision models maximize outcomes over long term planning horizons, while accounting for near term needs, resulting in more strategic decisions (Gregory et al. 2012). A decision analytic approach can evaluate alternate management and policy options, assess trade-offs, and identify optimal solutions and strategies (Huang et al. 2011; Linkov et al. 2006; White et al. 2012).

The main project objectives are to: 1) identify a suite of cesspool replacement options, 2) develop a range of management alternatives to upgrade cesspools that incorporate feasibility, 3) analyze environmental benefit of each alternative; 4) enumerate costs of the alternatives; and 5) provide recommendations on the alternatives relative to cost, environmental benefit, and stakeholder-identified objectives. Overarching strategic goals are to begin building the framework for a much better academic-agency collaboration, and to pilot a collaborative decision-making framework with communities that will have pay-offs for agency decision making far into the future. Hopefully recommendations from this report can help the DoH craft proposed legislation and administrative action to the benefit of the people and environment of Hawaiʻi.

Approach

Decision analysis

At the request of the Hawaii Department of Health (DoH), we undertook a decision analysis process to evaluate the utility of proposed actions to address groundwater nitrogen pollution in Upcountry Maui. This process involved convening a local stakeholder group (Appendix I) and collaboratively engaging in a structured decision-making process. Stakeholders were identified via conversations with the DoH, and via emails from public comments on a DoH Upcountry Maui groundwater investigation report and public presentation (DOH, 2018). The Upcountry Maui Stakeholder Group consisted of 28 people, representing the state DoH, the county departments of water supply and environmental management, elected officials, farmers, ranchers, large landowners, concerned citizens and environmental groups.

The structured decision-making process involves seven steps, consistent with a decision-theoretic process. Below we summarize the following steps:

1. Define problem
2. Define objectives and select metrics
3. Identify, cost and map feasible options (and constraints)
4. Screen options
5. Develop alternatives
6. Estimate consequences (accounting for local preferences and values)
7. Consider trade-offs

All analysis was conducted in R Version 3.5.0 (R Core Team 2018) and ArcGIS 10.2.2 (ESRI 2017) unless otherwise specified.

Step 1. Problem Statement

A problem statement addresses:

- What is the decision—what kind of action needs to be taken?
- What triggered this decision; why does it matter?
- Who is the decision maker?
- What is the decision timing and frequency; are other decisions linked to this one?
- What is the scope of the problem (how broad or complicated is it)?

- What are the legal context and constraints?

Recent sampling data results and analysis have indicated elevated concentrations of nitrate in the aquifer underlying Upcountry Maui. These levels are approaching U.S. Environmental Protection Agency (EPA) safe drinking water standards in certain places (https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations). DOH views these nitrate concentrations approaching the Maximum Contaminant Levels (10mg/L Nitrate – measured as Nitrogen) as a significant groundwater contamination problem.

Because DOH is charged with protecting scarce freshwater resources, it is obligated to work to correct the source of contamination. DOH identified Upcountry Maui as a Priority 1 area for cesspool conversion (DOH, 2017). The DOH report to Legislature recommends immediate conversion, although there is no legal or regulatory requirement for the cesspools in Upcountry Maui to be upgraded any sooner than cesspools elsewhere in the State under this recommendation. Priority 1 designation (including Upcountry Maui) have priority for funds in the event that public funding was to become available.

Independently, in 2017, the State of Hawaii passed Act 125 which mandated that all cesspools across the State be eliminated by 2050 to address water quality challenges.

DoH is empowered to: make recommendations for action to the Hawaii State legislature, regulate cesspool upgrade options, and seek funding to address water quality in Upcountry Maui, and throughout the State, from other government sources, including infrastructure funds, depending on the actions proposed. DoH is also tasked with monitoring and enforcing any statutory or legislative actions that may be required.

The State of Hawaii is empowered to pass new regulations. These include regulations that might assign funding, other incentives such as tax breaks, or penalties. They are also empowered to cost-share national infrastructure projects. The County of Maui can also cost-share state and national infrastructure projects, and is empowered to install sewer, change zoning, and manage permitting of new infrastructure, which could facilitate or limit future developments.

The community wishes to ensure that the burden for wastewater management is equitably shared among residents, and between residents, developers, and other parties. Parties do not all agree on what equity looks like. Some think that means that developers should pay, others that polluters should pay.

Parties recognize that options for transitioning from cesspools to alternate waste management systems can involve large costs, and result in widely varying improvements to water quality depending on their type and site conditions. Some transition options may take a long time to realize. Since technology moves fast, and both efficacy and cost change rapidly, in that timeframe, the landscape of management options may change drastically – with possibly better management and more economical options available in future. Consequently, there may seem to be little incentive, particularly for individuals, to act now. However, dealing with the scale of change required means that action and planning is necessary now, particularly as large-scale infrastructure options may be required, and some may become less feasible over time.

It is also recognized that the estimated costs are likely to be significant, so a range of feasible options with different costs are desirable for affected individuals as well as options that could take the burden from individuals due to eligibility for public funding or possibly commercial investment.

A range of management options are likely feasible, but those that are possible in Upcountry Maui have not yet been identified or costed. To address this data gap, the University of Hawaii is leading a process to identify, screen, and cost options to address nitrate contamination in Upcountry Maui groundwater. Existing design regulations and approval processes based on engineering and regulatory constraints exist for some options but not others; where these are not available, one constraint to implementation is that an approval phase would be required.

To address this problem, we applied a structured decision-making process as a tool to work through and address the issues associated with groundwater management in Upcountry Maui. UH worked with a DoH-developed groundwater model to evaluate the effects of several alternatives, and with local stakeholders to develop objectives that reflect their goals, including protection of public health, and finally to evaluate the cost effectiveness of the alternatives.

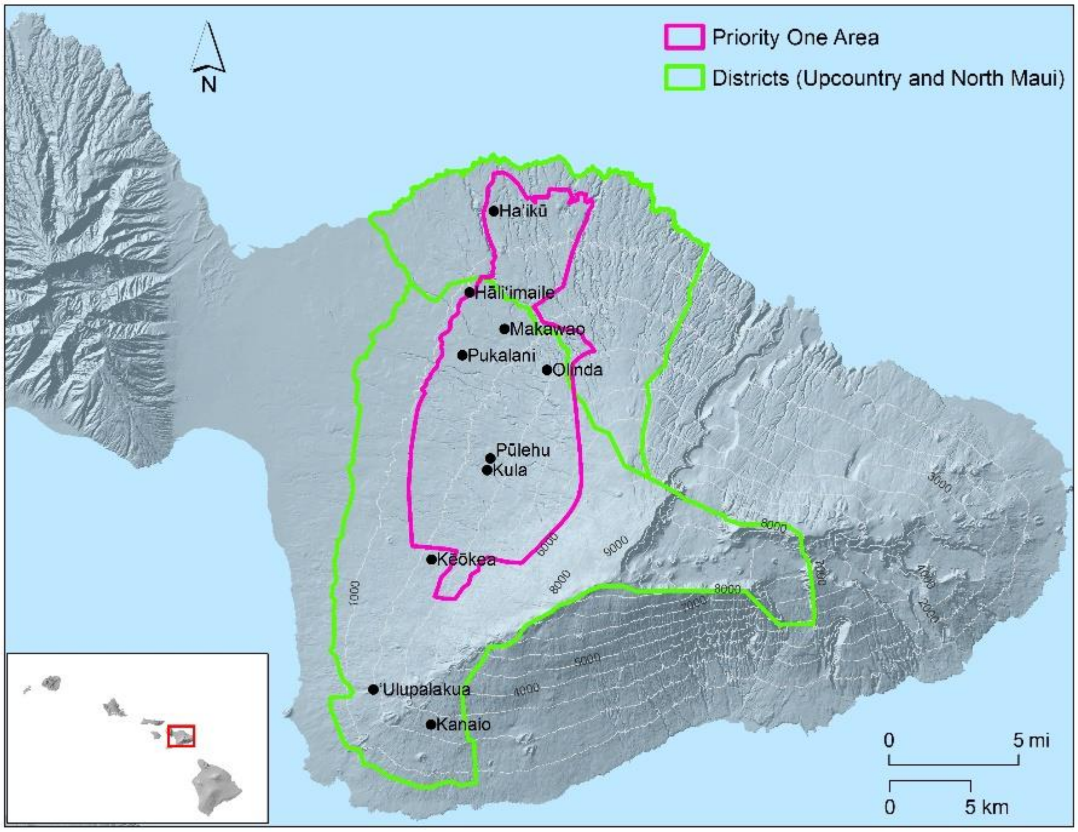

Figure 1. Maui study area; study focuses on cesspool upgrade options for priority areas in Upcountry and North Maui. Priority One Area was identified by DOH, based on elevated nitrate concentrations in the Upcountry Maui groundwater and Statewide analysis (Whittier and El-Kadi 2014).

Additional Concerns/Considerations related to the problem statement

It is important to note that the stakeholder working group participants voiced fundamental disagreement with the key underlying premises of the problem. This project started from the fact that Upcountry Maui is a Priority 1 area, and its aims were to identify cost-effective and technically feasible options to upgrade cesspools in the area. Many of the stakeholders strongly disagreed with the prioritization of Upcountry for a number of reasons. They argued that that nitrogen flux from cesspools is a minor contributor compared to other sources; nitrogen from cesspools doesn't reach the groundwater; nitrogen loads in the groundwater are below drinking water standards nearly everywhere; evidence of contamination is limited to a handful of samples in a discrete area; no Upcountry residents get their water from the aquifer so drinking water standards aren't applicable; the only users of the aquifer for drinking water are private for-profit developers who choose not to wait for municipal water supply; and there is no documented evidence of human health/stream/coastal impacts. One stakeholder raised the concern that municipal drinking water in Upcountry Maui included large amounts of chloramine, a chemical that may lead to increased nitrogen under the right circumstances. This issue was beyond the scope of this analysis, however, disinfectant residuals in drinking water are generally very low due to cost concerns and regulations (less than 0.5 mg/L). Still, inputs of chloramine into drinking water and thus emissions via cesspools should be further investigated, and, if appropriate, incorporated into the groundwater model. The project team were able to use empirical evidence and modeling to discuss some of these valid arguments, but the issue of prioritization remains a thorny one that is outside the scope of this analysis.

Step 2. Objectives and metrics

Objectives were developed by the project team based on a series of consultations with members of the Upcountry Maui Stakeholder Group, including a site visit and one-on-one conversations with many members of the stakeholder group (Appendix I). We developed metrics to measure each objective (Table 1).

Table 1. Objectives for groundwater nitrogen management and the metrics developed to evaluate them.

	Objective	**Metric**
O1.	Minimize costs	Costs (C) = Net present value of cost in USD 2018
O2.	Minimize costs to community (individual households, and the community overall)	Mean cost (USD 2018) per 12,000 Upcountry Maui households over the 60-year cost horizon
O3.	Meet State and EPA drinking water quality standards.	State and EPA drinking water standards applied to groundwater: maximum concentration simulated by groundwater model is below 10mg/L nitrogen, measured as area under 10mg/L
O4.	Minimize aquifer nutrient loading	Benefit (B) = change in nitrogen mass flux resulting from intervention
O5.	Minimize risk to drinking water aquifers	Final groundwater N concentration below 5mg/L, measured by area over 5mg/L
O6.	Maximize cost-efficiency in minimizing nutrient pollution	Cost efficiency (CE) = B/C
O7.	Maximize equity	1: Number of households implicated in alternative 2: Worst polluters
O8.	Maximize equity Maui wide	Difference in cost per household of upgrade per annum and mean sewer fees per annum across Maui
O9.	Meets existing design standards	Proportion of N reduction contributed by not yet approved technologies? For options, matrix of Yes/No
O10	Minimizes Maintenance Burden	Qualitative classification conducted by engineers (High, Medium or Low levels of maintenance)

Additional Concerns/Considerations related to Fairness and Equity

In SDM, alternative courses of action are assessed against the objectives to guide the decision. As noted in the problem statement, this analysis is focused on finding alternatives to upgrade the cesspools within Upcountry Maui, therefore some concerns and considerations could not be adequately captured at this scale. We discuss these below.

Stakeholders raised concerns about fairness at two scales: within their community and more broadly at the county level. Stakeholders perceived an unfair burden to the homeowners compared to their other households with cesspools in Upcountry Maui, other Maui residents, including those with cesspools in “non-priority areas,” as well as households who have the good fortune to be hooked up to the public sewer system. These concerns boil down to three questions: (1) Why should I have to pay if my neighbors aren’t? (2) Why should I have to pay if I am not the problem? (3) Why should I have to pay more than other people on Maui for my household waste disposal? We have tried to incorporate all three of these though Objectives 7 and 8.

An additional dimension of equity arose as some stakeholders believed that their long-term use of the ground as a receptacle for household wastewater only became a problem when developers starting tapping the groundwater to provide drinking water to new homes. Some felt that these developers should bear some (or all) of the costs of preserving the groundwater quality, as they were the ones privately profiting from the public good. Many stakeholders also doubted the relative importance of cesspools as a pollution source, compared to other offenders, such as agriculture. Indeed, legacy nitrogen from former sugarcane production is the largest current contributor to nitrogen in the broader area. However, little can be done about this source at this point – the legacy nitrogen is needs to work its way through the system, while cesspools are actively polluting the groundwater.

Step 3. Identify, cost, map options

Various cesspool upgrade options are available, and these are reviewed in more depth in Appendix II. The general categories of options include the following:

- **Treatment systems**: these typically provide primary (physical) or secondary (including biological) treatment of raw household wastewater. Treatment systems include septic tanks and aerobic treatment units capable of nitrification and/or denitrification.

- **Disposal systems:** these are paired with a treatment system as the means for appropriately disposing treated wastewater. Examples of disposal systems are absorption systems (leach fields), seepage pits, and Presby Advanced Eniro-Septic®, which also includes a treatment component.

- **Technologies requiring approval under the Hawaii Administrative Rules (HAR):** these are feasible options included in the HAR, but require additional approval of specific designs and specifications. Examples of these options are evapotranspiration and recirculating sand filters.

- **Innovative technologies:** although these are not included in the HAR and will require more extensive review and certifications, they have potential as cesspool replacements. These types of technologies consist of either treatment and disposal options such as constructed wetlands, drip irrigation, and novel commercial systems such as Eliminite and NITREX.

- **Emerging technologies:** these have been tested experimentally or in pilot field tests and have promising results. Many of these options are passive, requiring little or no maintenance. Methods include recirculating gravel filter systems, layered soil treatment systems, and nitrification/denitrification biofilters. More extensive studies, especially on their performance on Maui, will be necessary.

- **Alternative toilets:** compost toilets are commercially available and incinerating toilets are in development. These are essentially zero-discharge systems with proper operation and maintenance. This allows for a home to set up a graywater (discharges not from toilets and kitchen sinks) reuse system. A wastewater treatment disposal system must still be present, however, because the State of Hawaii requires graywater to have an overflow pathway to prevent spills.

- **Sewering:** homes can be connected via sewers in decentralized or centralized sanitary sewer system. In a decentralized system, groups of homes connected via a cluster system may have a satellite treatment facility and/or a common disposal system. This could be extended to a centralized system with more homes connected to a wastewater treatment plant.

Table 2 shows the treatment and disposal options considered in this study (descriptions are found in Appendix II). Table 2 also shows the annual operation and maintenance costs which are considered independent of system size. Operation costs are for electricity and thus only those systems that require power have an operation cost. Electricity costs are generally very small for these systems (assumed 100W power draw, $0.35/KWH, thus $25/mo). Maintenance costs are for inspection by a professional ($150) and for pumping/hauling/disposal of accumulated solids ($250). Most of the systems are assumed to last for either 30 or 60 years, at which time they will have to be replaced. This affects the 60-yr life cycle cost which is discussed further below.

Table Annual costs for operation and maintenance of OSDS treatment and disposal systems including replacement intervals

	OSDS Treatment and Disposal Systems	Operation	Maintenance	Replacement interval (yrs)
Treatment Options	ATU-N	$300	$400	30
	ATU-N/DN	$300	$400	30
	Septic Tank	$0	$400	60
	Passive Biofilters (in-ground, medium, FL)	$0	$400	60
	Passive Biofilters (in-ground, high, FL)	$0	$400	60
	Composting toilets (also use for incinerating)	$300	$400	30
Disposal Options	Absorption System (bed or trench)	$0	0	60
	Constructed Wetland	$0	$400	30
	Disinfection	$150	$50	20
	Drip Irrigation	$300	$150	30
	Seepage Pit (new)	$0	$400	60
	Evapotranspiration	$0	$150	60
	NITREX ®	$0	$400	30
	Presby Advanced Enviro-Septic & De-Nyte ®	$0	$125	60
	Recirculating Sand Filter	$300	$400	30
	Eliminite ®	$300	$150	30
	Layered Soil Treatment System (MA)	$300	$150	60
	Gray Water system	$0	$150	30

Additional Concerns/Considerations related to management burden of upgrades

Another concern is program management by the DOH. The DOH WWB is tasked with approving and managing OSDSs. Currently, OSDSs statewide are managed at the time of design/approval/installation and there are no resources for on-going management of the approximately 100,000 systems. The cesspool ban will mean that 88,000 systems will be upgraded and each will have to go through the approval process which includes review and approval of test data and design submittals from engineers, and keeping of records. This will be a huge task that would require several additional staff. In addition, it will become even more important for the DOH to implement a more comprehensive life-cycle type management program for OSDSs. Previous work by the investigator used USEPA guidance documents to establish minimum maintenance, performance and inspection standards for OSDSs in Hawaii. The recommended model was to issue, monitor, and enforce 2-yr cycle OSDS operating permits to homeowners, and to certify and license OSDS service providers and OSDS inspectors. The items produced included a model law, a management program framework and roles of all parties, minimum maintenance requirements, inspection checksheets & protocols, and application/renewal forms.

Step 4. Screen options

Each treatment and each disposal system has its own constraints and necessary site conditions, including groundwater elevation, lot size, soil percolation rate, topographic slope, location in a flood zone, proximity to inland or coastal waters, and surrounding density of cesspools (Table). The characteristics and conditions of a site determine the feasibility of installing a given system at that site. For example, an absorption system can only be installed in an area with a slope of <12 percent, and a septic tank should be installed outside a flood zone and in an area not in proximity to the coast. It should be noted that while the feasibility of disposal systems are typically constrained by site conditions, treatment systems can generally be installed at any site independent of site conditions (WRRC, 2008).

For each of the properties (TMKs) containing OSDS in the Upcountry Maui study area, we assessed the feasibility of each of the upgrade options considered, using geospatial data corresponding to the constraints. Publicly available spatial data for OSDS, TMKs, terrain slope, coastline, streams, and flood zones were obtained from the Hawaii Statewide GIS Program Data Portal (http://geoportal.hawaii.gov/; see Table 4 for dataset details). Data representing each of the site conditions were attributed to each OSDS point datum. A series of conditional statements were then applied in order to filter OSDS points by the constraints of a given system (Table), to determine whether a given upgrade option was feasible for the site conditions of each OSDS.

Table 3. Constraints of system options. Y: Option is feasible, N: Option is not feasible/permitted; HAR 11-62; [1]These are included as options in the HAR 11-62, but require additional review and approval. [2] ATU-N/DN and absorption systems used together with UV disinfection are assumed to be permitted for TMKs that are located < 50 feet from a body of water.

	Site Conditions/Constraints	**High water table**	**Small Lot Size**	**Slow Soil Percolation Rate**	**High Topographic Slope**	**In Flood Zone**	**Near Inland or Coastal Waters**
Options Category	**Options**						
Treatment	Septic Tank	Y	Y	Y	Y	N	Y if >50 ft away
Treatment	ATU, N or N/DN	Y	Y	Y	Y	N	Y if >50 ft away[2]
Disposal	Absorption Systems (Bed/Trench)	Y if >3 ft	Y if >minimum absorption area required by HAR	Y if 60 to 1 min/in	Y if <12% (Trench used if 8% <slope <12%)	N	Y if >50 ft away[2]
Disposal	Seepage Pit	Y if >3 ft	Y	Y if 60 to 1 min/in	Y if ≥ 12% and absorption system not feasible	N	Y if >50 ft away
Treatment	Chlorine Disinfection	Y	Y	Y	Y	N	Y if >50 ft away
Treatment	UV Disinfection	Y	Y	Y	Y	N	Y
Disposal	Presby Advanced Enviro-Septic and De-Nyte	Y	Y if >minimum absorption area required by HAR	Y if 60 to 1 min/in	Y	N	Y if >50 ft away
Approval Required[1]	Evapotranspiration	Y	Y	Y	Y if <12%	N	Y if >50 ft away
Approval Required[1]	Recirculating Sand Filter	Y	Y	Y	Y	N	Y if >50 ft away
Innovative Technologies	Constructed Wetland	Y if >3 ft	Y	Y	Y if <12%	N	Y if >50 ft away

Options Category	Site Conditions/Constraints Options	High water table	Small Lot Size	Slow Soil Percolation Rate	High Topographic Slope	In Flood Zone	Near Inland or Coastal Waters
Innovative Technologies	Drip Irrigation	Y	Y if >minimum absorption area required by HAR	Y	Y	N	Y if >50 ft away
Innovative Technologies	Eliminite	Y	Y	Y	Y	N	Y if >50 ft away
Innovative Technologies	NITREX	Y	Y	Y	Y	N	Y if >50 ft away
Emerging Technologies	Recirculating Gravel Filter System (WA)	Y	Y	Y	Y	N	Y if >50 ft away
Emerging Technologies	Passive Treatment Units (medium and high treatment) (FL)	Y	Y	Y	Y	N	Y if >50 ft away
Emerging Technologies	Disposal by Layered Soil Treatment ("Layer Cake") Systems (MA)	Y if >3 ft	Y	Y	Y if <12%	N	Y if >50 ft away
Emerging Technologies	Disposal by Nitrification/Denitrification Biofilter (NY)	Y	Y	Y	Y	N	Y if >50 ft away
Alternative Toilets	Compost/Incinerating/ Nano-Membrane Toilets	Y	Y	Y	Y	Y	Y
Sewering	Decentralized/Centralized	Y	Y	Y	Y	Y	Y

Table 4. Geo datasets used in feasibility evaluation

Constraint	Dataset	Geoprocessing
Slope	Hawaii Statewide DEM 5-meter	ArcMap Spatial Analyst Toolbox: Slope tool
Streams (distance from)	Streams (from DLNR, Division of Aquatic Resources)	Near tool; generates distance of each TMK from stream polylines
Coastline	Coastlines MHI (from Office of Planning, State of Hawaii)	Polygon to Polyline Conversion tool. Near tool; generates distance of each TMK from coastline polylines
Lot size	Parcel/TMK maps for Neighbor Islands (from Statewide GIS Program, Office of Planning, State of Hawaii)	Calculate geometry: Area
Area available for absorption-type systems	Parcel/TMK maps for Neighbor Islands (from Statewide GIS Program, Office of Planning, State of Hawaii)	Calculate geometry: Area. Subtract house size: • For lots V5000 sf: house ≤50% lot size • For lots >5000 sf: house = 3000 sf
Flood zone	FEMA Special Flood Hazard Areas for the State of Hawaii	Spatial Join: • Join features: flood data (field of interest: FLD_ZONE) • Target features: OSDS • Screening: FLD_ZONE ≠ "x" (areas outside the 1-percent annual chance floodplain and areas protected from the 1-percent annual chance flood by levees"

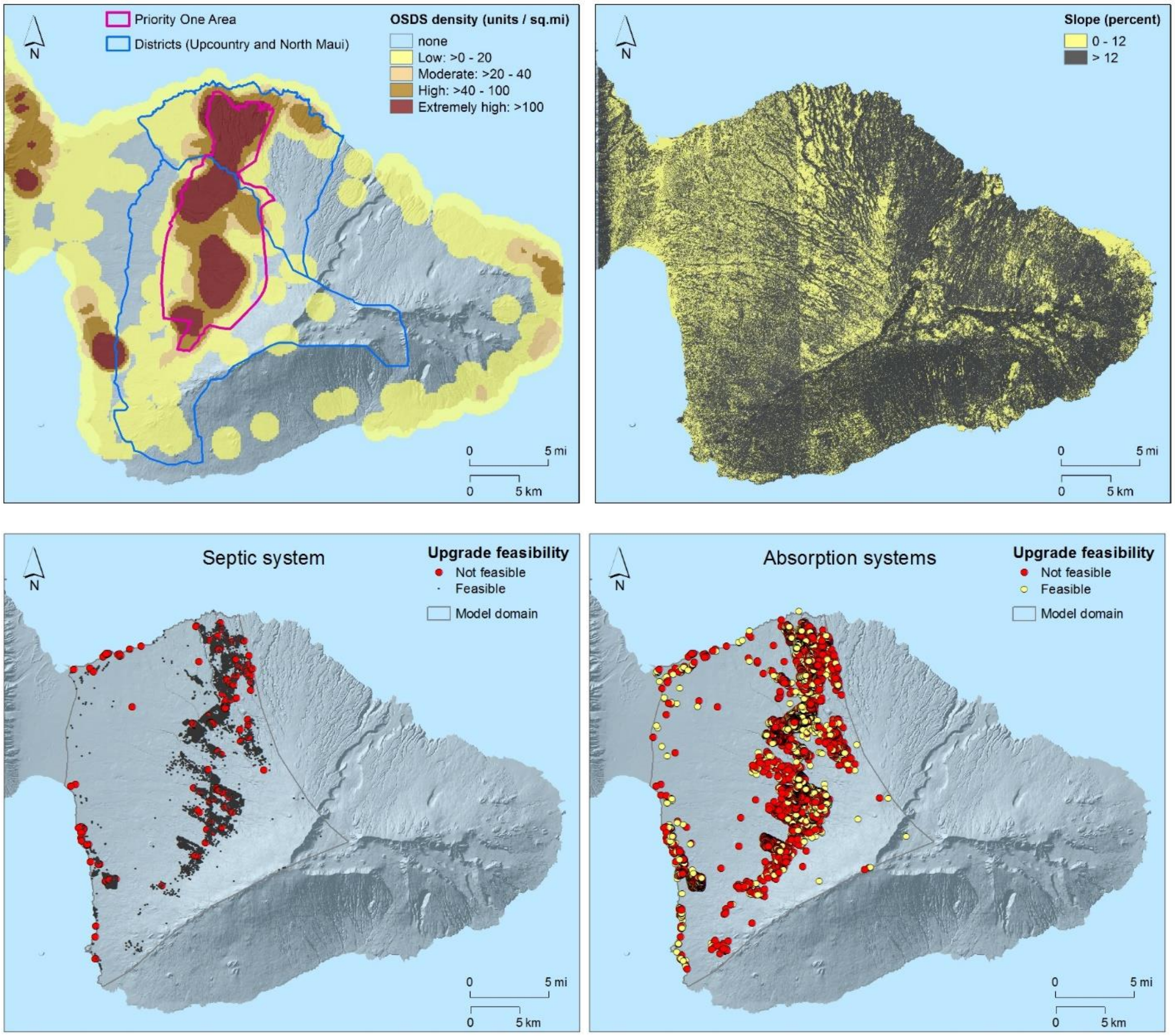

Figure 2. Disposal options evaluated were constrained by the site limitations.

__Additional Concerns/Considerations related to technical options__

Some options present technical considerations that are quite specific, and outside of the technical review. For instance, households with alternative (zero-discharge: composting or nano/Gates) toilets will also have to deal with other wastewater flows (other than toilets). Household wastewater consists of black water and gray water. According to the Guidelines for the Reuse of Gray Water (HDOH Wastewater Branch, 2009), black water is defined as wastewater discharged from toilets, urinals, and food preparation sinks (kitchen sinks). Gray water is defined as wastewater discharge from: showers and bathtubs, hand-washing lavatories, sinks (not used for disposal of hazardous, toxic materials food preparation, or food disposal), and clothes-washing machines (excluding wash water with human excreta, e.g., diapers). Gray water reuse is not currently permitted in the County of Maui, and the current

HDOH Guidelines require a wastewater treatment system. As stated in the Guidelines, a gray water reuse system must have an overflow pathway to the county sewer system or an individual wastewater treatment system. Thus, there are two issues for current cesspool systems that upgrade to zero-discharge toilets: 1) kitchen sink water is considered black water that would still require an OSDS, and 2) all gray water systems require an overflow pathway for flows in excess of that needed for in-yard reuse to prevent overflow/spills. It is possible that the overflow issue (2) could be handled by a seepage pit (converted cesspool). However, the kitchen sink blackwater issue (1) would necessitate a change in the guidelines in order remove the need for an approved OSDS system (cesspool upgrade). A gray water system is simply a storage tank and an irrigation system and does not include any type of “treatment” for removal of items washed down the kitchen sink. Thus, the sticking point is that kitchen sink use would have to be strictly controlled (including banning in-sink grinders) or else the gray water tank would end up rapidly accumulating every manner of ground up materials discharged and these materials would be subject to biodegradation, septic conditions, odors, etc. The most practical solution would be source control – but this would require a fairly major change in human behaviour and that may not happen with the necessary reliably. Maui County would also have to adopt a rule allowing gray water systems.

Stakeholders were concerned that many of the geographically extensive options would either not fit on the properties or require destruction of gardens, many of which provide sustenance and income to Upcountry Maui residents. Nearly all of the properties in the study area have enough space for one or more alternative cesspool upgrade systems, but nearly all do require significantly more space than cesspools. However, these systems are all located underground and do not preclude co-location of gardens on top if necessary. If a resident had a health concern in such a situation, a raised-bed garden with an impermeable bottom liner could be utilized.

Step 5. Alternatives

Alternatives are treatment+disposal options packaged together that could be implemented across the study area. Creating and evaluating a range of well-defined internally coherent alternatives (or packages of management and policy actions) is central to good decision-making. Good alternatives should be collaborative to ensure the full range of stakeholder priorities are captured in the alternatives developed and evaluated. To support this process, we undertook alternatives development in two phases.

In the initial phase, using feedback from stakeholder consultations, the project team developed simple alternatives that allowed stakeholders to explore “what if” scenarios without needing to specify exact design details, and a set of alternatives based on several discussions with stakeholders that captured the suite of options available (see Appendix II), and ensured options relevant to the full range or stakeholders were incorporated. In the second phase, to ensure stakeholder needs were addressed, we conducted a facilitated alternative development workshop (combined in person and online) with the stakeholder group. The workshop included 13 participants, including members of the upcountry Maui community associations, Maui County Council, Maui County Farm Bureau, Agricultural Working Group, and Hawaii Department of Health. The University of Hawaii Institutional Review Board advised that human subjects clearance was not required for this process, however we handed out informational sheets to all participants explaining the purpose and approach of the project, with contact information should participants feel the need to follow up with the Principal Investigators or UH’s IRB.

In the stakeholder workshops we conducted two focused alternative development activities, where we worked with groups of stakeholders to develop alternatives. The two activities, (1) Bookends, and (2) Visioning, are described below. Notes from this process are provided in Appendix III.

1. Bookends: To explore the implications of focusing on each objective, we asked three groups of stakeholders to think of and define a strategy that they believed would perform ‘AMAZINGLY’, for each objective, with no consideration of other implications – a modified application of a “bookends” approach (Gregory 2012). Subsequently participants were asked to consider how they thought the selected strategy or strategies would perform against other criteria and with that in mind, to consider whether other options might perform equally well for the objective under consideration, but better against other objectives.

2. Visioning: We asked stakeholders to construct alternatives for two situations (A and B) below. Participants were asked to focus on ‘out-of the-box’ options, and to identify and record risks, challenges or barriers, rather than dismissing ideas due to perceived barriers or novelty.
   A. Everybody wins: Here we asked participants to build on the first activity to identify solutions that might improve performance against all objectives, identify potential

barriers or reasons why a solution may not perform well against all criteria, and then focus on how they might be overcome, or what other options or tweaks might perform better across the board.

B. Funding potential: Here we asked participants to focus on options that would reduce or remove costs to the homeowner or leverage opportunities for other funding.

Subsequent to these activities, the project team developed a set of 38 alternatives that captured the full decision space (see Table 5). To construct these alternative, options were screened for feasibility (as per methods described in “Constraints”) to inform the spatial allocation of options within alternatives, such that only options screened as feasible for a given site could be selected for that site. Alternative development included consideration of options that would be implemented under a range of feasibility constraints. The results of the screening process for each alternative for each TMK are shown in Table 6. A few things can be highlighted from Tables 5 and 6 as follows:

- Alt4B (septic tank + seepage pit) has the least nitrogen removal at only 10%. Other septic tank Alts have nitrogen removal efficiencies of 47% to 98%
- The Alts that incorporate ATUs with nitrification only, have removals from 53% to 71% (plus a zero-discharge option (ET) which gives 100% removal)
- The Alts that incorporate ATUs with nitrification + denitrification, have removals from 50% to 71%. These could also add ET for 100% removal.
- The data set that was used for this study includes 11,956 TMKs in the study area, however, only 8,540 have OSDSs and of those, there are 6,198 that have cesspools. These numbers are somewhat different than the DOH references (10,040 OSDSs and 7,400 cesspools)
- The maximum slope constraint of 12% affects absorption disposal systems for many of the TMKs with cesspools. Absorption disposal systems can only be used on 3,394 of the TMKs. For the other 2,804 TMKs with cesspools, the existing cesspool can be cleaned and converted into a seepage pit (Alt4B). Thus, for septic tank Alts, the fallback option is Alt4B (septic tank + seepage pit), and for ATU Alts, the fallback option is Alt16 (ATU-N/DN + disinfection + seepage pit).
- Sewering Makawao will result in closure of 1,712 cesspools
- Sewering the remainder of Pukalani will result in closure of 1,217 cesspools
- Sewering both Pukalani and Makawao will result in 2,929 cesspools

Table 5. Alternatives considered

Code	Name	Description
1	Septic Tank to Absorption System: 47% Reduction	47% uniform reduction in N (mg/L) outputs at each Household.
2	Septic Tank to Constructed Wetland: 53% Reduction	53% uniform reduction in N (mg/L) outputs at each Household.
3	Septic Tank to RSF to Drip Irrigation: 69% Reduction	69% uniform reduction in N (mg/L) outputs at each Household.
4	Septic Tank to RSF to Seepage Pit: 47% Reduction	47% uniform reduction in N (mg/L) outputs at each Household.
4B	Septic Tank to Seepage Pit: 10% Reduction	10% uniform reduction in N (mg/L) outputs at each Household.
5	Septic Tank to Eliminite to Absorption System: 80% Reduction	80% uniform reduction in N (mg/L) outputs at each Household.
6	Septic Tank to Presby: 78% Reduction	78% uniform reduction in N (mg/L) outputs at each Household.
7	Septic Tank to NITREX to Absorption System: 98% Reduction	98% uniform reduction in N (mg/L) outputs at each Household.
8	Septic Tank to Recirculating Gravel Filter System to Absorption System: 84% Reduction	84% uniform reduction in N (mg/L) outputs at each Household.
9	Septic Tank to "Layer Cake": 55% Reduction	55% uniform reduction in N (mg/L) outputs at each Household.
10	Septic Tank to Lined/Sequence D/DN Biofilter: 91% Reduction	91% uniform reduction in N (mg/L) outputs at each Household.
11	ATU-N to Absorption System: 53% Reduction	53% uniform reduction in N (mg/L) outputs at each Household.
12	ATU-N/DN to Absorption System: 71% Reduction	71% uniform reduction in N (mg/L) outputs at each Household.
13	ATU-N to Constructed Wetland: 58% Reduction	58% uniform reduction in N (mg/L) outputs at each Household.
14	ATU-N to ET: 100% Reduction	100% uniform reduction in N (mg/L) outputs at each Household.
15	ATU-N to Disinfection to Drip Irrigation: 71% Reduction	71% uniform reduction in N (mg/L) outputs at each Household.
16	ATU-N/DN to Disinfection to Seepage Pit: 50% Reduction	50% uniform reduction in N (mg/L) outputs at each Household.
17	Passive FL Units (medium, in-ground): 71% Reduction	71% uniform reduction in N (mg/L) outputs at each Household.
18	Passive FL Units (high) to Absorption System: 91% Reduction	91% uniform reduction in N (mg/L) outputs at each Household.

19	High Impact	The 20% worst offenders (by N flux) upgrade to best N reduction option.
20	Private Company pays for installation, then fees	Decentralised Treatment Units are installed in very high density areas. Elsewhere: the cheapest feasible traditional option (i.e. cheapest from alts 1-18 is applied). Regulatory changes require any new developments above same density (or lower) to incorporate.
21	O&M borne by users (cost of O&M)	
22	Fed infrastructure fund + State + Maui County - Fees = same as rest of Maui	
23	Private Company pays for installation, then fees	Decentralised Treatment Units are installed in very high density areas. Elsewhere: the a very effective option is applied (Membrane Bioreactor). Regulatory changes require any new developments above same density (or lower) to incorporate .
24	O&M borne by users (cost of O&M)	
25	Fed infrastructure fund + State + Maui County - Fees = same as rest of Maui	
26	Private Company pays for installation, then fees	Sewer all sites in MAKAWAO. Estimate costs based on roughly the capcaity needed based on that volume/ density + a guess at how much extra might appear in build out.
27	O&M borne by users (cost of O&M)	
28	Fed infrastructure fund + State + Maui County - Fees = same as rest of Maui	
29	Private Company pays for installation, then fees	Sewer all sites in Pukalani not already on sewer. Estimate costs based on rough costs of upgrades.
30	O&M borne by users (cost of O&M)	
31	Fed infrastructure fund + State + Maui County - Fees = same as rest of Maui	
32	Private Company pays for installation, then fees	Sewer all sites in Makawao + Pukalani not already on.
33	O&M borne by users (cost of O&M)	
34	Fed infrastructure fund + State + Maui County - Fees = same as rest of Maui	
35	Well head treatment: 0% Reduction	No change in groundwater nitrogen concentration. Water is drinkable at tap. User pays (no cost to householders for sewer, but there would be a cost passed on to those who use the water).
36-38	Composting Toilet (1-3): 100% Reduction	Everyone gets a composting toilet (as for 1-19). 1. Modify grey water rules and have grey

		water system overflow into existing system.
		2. Modify grey water rules and have grey water system overflow into cesspool or existing unit
		3.Modify grey water rules and have grey water system overflow into the minimum feasible solution - seepage pit.

[1] If the alternative disposal option was not feasible, the second choice was the same alternative treatment with an absorption system, and the third choice was the same alternative treatment with a seepage pit. About 150 TMKs are located less than 50 feet from a body of water. The upgrade option for these TMKs is ATU N/DN with UV disinfection and an absorption system.

Table 6. Summary results of alternatives screening

Alt #	Alternative	TMKs					Type of Upgrade		
		# of TMKs Total in Area	# of TMKs with OSDSs	# of TMKs with Cesspools	# of TMKs with cesspools Upgraded	# of TMKs connected to Sewer	a	b	c
0	Baseline conditions with cesspools	11,956	8,540	6,198	6,198	0	N/A	N/A	N/A
1	Septic Tank to Absorption System: 47% Reduction	11,956	8,540	6,198	6,198	0	Alt1 3394	Alt4B 2804	N/A
2	Septic Tank to Constructed Wetland: 53% Reduction	11,956	8,540	6,198	6,198	0	Alt2 3394	Alt4B 2804	N/A
3	Septic Tank to RSF to Drip Irrigation: 69% Reduction	11,956	8,540	6,198	6,198	0	Al3 6198	N/A	N/A
4	Septic Tank to RSF to Seepage Pit: 47% Reduction	11,956	8,540	6,198	6,198	0	Al4 6198	N/A	N/A
4B	Septic Tank to Seepage Pit: 10% Reduction (1.5 BR; 70 gal/person)	11,956	8,540	6,198	6,198	0	Al4B 6198	N/A	N/A
4B_HI	Septic Tank to Seepage Pit: 10% Reduction (2/BR; 100 gal/person)	11,956	8,540	6,198	6,198	0	Al4B 6198	N/A	N/A
4B_LO	Septic Tank to Seepage Pit: 10% Reduction (1/BR; 70 gal/person)	11,956	8,540	6,198	6,198	0	Al4B 6198	N/A	N/A
4B_Census	Septic Tank to Seepage Pit: 10% Reduction (2010 census/no. BR; 100 gal/person)	11,956	8,540	6,198	6,198	0	Al4B 6198	N/A	N/A
5	Septic Tank to Eliminite to Absorption System: 80% Reduction	11,956	8,540	6,198	6,198	0	Alt5 3394	Alt4B 2804	N/A
6	Septic Tank to Presby: 78% Reduction	11,956	8,540	6,198	6,198	0	Alt6 3394	Alt4B 2804	N/A
7	Septic Tank to NITREX to Absorption System: 98% Reduction	11,956	8,540	6,198	6,198	0	Alt7 3394	Alt4B 2804	N/A
8	Septic Tank to Recirculating Gravel Filter System to Absorption System: 84% Reduction	11,956	8,540	6,198	6,198	0	Alt8 3394	Alt4B 2804	N/A
9	Septic Tank to "Layer Cake": 55% Reduction	11,956	8,540	6,198	6,198	0	Alt9 3394	Alt4B 2804	N/A
10	Septic Tank to Lined/Sequence D/DN Biofilter: 91% Reduction	11,956	8,540	6,198	6,198	0	Alt10 3394	Alt4B 2804	N/A
11	ATU-N to Absorption System: 53% Reduction	11,956	8,540	6,198	6,198	0	Alt11 3394	Alt16 2804	N/A
12	ATU-N/DN to Absorption System: 71% Reduction	11,956	8,540	6,198	6,198	0	Alt12 3394	Alt16 2804	N/A
13	ATU-N to Constructed Wetland: 58% Reduction	11,956	8,540	6,198	6,198	0	Alt13 3394	Alt16 2804	N/A
14	ATU-N to ET: 100% Reduction	11,956	8,540	6,198	6,198	0	Alt14 3394	Alt16 2804	N/A
15	ATU-N to Disinfection to Drip Irrigation: 71% Reduction	11,956	8,540	6,198	6,198	0	Al15 6198	N/A	N/A
16	ATU-N/DN to Disinfection to Seepage Pit: 50% Reduction	11,956	8,540	6,198	6,198	0	Alt16 2804	Alt12 3394	N/A
17	Passive FL Units (medium) to Absorption System: 71% Reduction	11,956	8,540	6,198	6,198	0	Alt17 3394	Alt16 2804	N/A
18	Passive FL Units (high) to Absorption System: 91% Reduction	11,956	8,540	6,198	6,198	0	Alt18 3394	Alt16 2804	N/A
19A	High impact: Septic Tank to Presby: 78% Reduction (highest mass reduction in alt 1-18)	11,956	8,540	6,198	1,839	0	Alt6 1023	Alt4B 816	N/A
19B	High Impact: ATU-N to ET: 100% Reduction (smallest area with >5 mg/L in alt 1-18)	11,956	8,540	6,198	1,871	0	Alt14 992	Alt16 847	N/A
20-21-22	Sewer Makawao, ST to Presby (cheapest option)	11,956	8,540	6,198	4,329	1,712	Alt6 2311	Alt4B 2383	Alt12 123
23A-24A-25A	Sewer Pukalani, ATU-N to ET (smallest area with >5 mg/L in alt 1-18) where possible	11,956	8,540	6,198	4,824	1,217	Alt16 2320	Alt14 2870	N/A
23B-24B-25B	Sewer Pukalani, ST to Presby (highest mass reduction in alt 1-18) where possible	11,956	8,540	6,198	4,824	1,217	Alt6 2948	Alt4B 2320	N/A
26-27-28	Sewer Makawao only, no cesspool upgrades	11,956	8,540	6,198	4,329	1,712	N/A	N/A	N/A
29-30-31	Sewer Pukalani only, no cesspool upgrades	11,956	8,540	6,198	6,198	1,217	N/A	N/A	N/A
32-33-34	Sewer Makawao & Pukalani, no other upgrades	11,956	8,540	6,198	6,198	2,929	N/A	N/A	N/A
35	Wellhead treatment (results same as base model)	11,956	8,540	6,198	6,198	0	N/A	N/A	N/A
36-37-38	Compost toilets, no effluent N	11,956	8,540	6,198	6,198	0	N/A	N/A	N/A

Step 6. Estimating consequences

Costs

For each cost objective (**Objectives 1 and 2**) we estimated both capital costs and operation and maintenance costs over a standardized 60-year time horizon. Capital costs for equipment were based on manufacturer/vendor price quotes and catalogues. Detailed itemized installation costs for equipment, labor, and professional services (engineering, plumbing, electrician) were based on discussions with contractors and service providers with many years of experience installing all types of on-site systems in Hawaii. Costs for equipment were based on quotes from Hawaii-based vendors and representatives.

Costs are based on the size of the OSDS system required for the number of bedrooms for each TMK at a rate of 200 gallons per day (gpd) per bedroom. Individual systems are limited by DOH rules to 1,000 gpd each (5 bedrooms). Size requirements for septic tanks, ATUs, absorption systems, and seepage pits were determined according to the requirements in HAR 11-62 Wastewater Systems. For other types, we used industry standard sizing criteria and unit costs. The size of the absorption systems is dependent upon soil percolation rates. The DOH WWBranch pulled a large set of permits for several areas of Upcountry Maui and we were able to determine typical percolation rates by area as follows:

- Haiku (15 to 30 min/inch)
- Kula (10 to 15 min/inch)
- Makawao (15 to 20 min/inch)
- Pukalani (15 min/inch)
- Design value used for all TMKs: 20 min/inch

This gives an area requirement of 175 square feet per bedroom assuming that plastic dome infiltrator units are used which receive a 17% area reduction. The values for estimated capital costs include labor, materials, equipment, mobilization, installation, contractor's overhead and profit, and construction contingencies. Operation and maintenance costs include electricity, maintenance inspections, and tank pumping/hauling/disposal, considered for a 60-year lifetime of the system, including replacements as necessary. Variations in cost may occur due to site conditions such as soil type (e.g., excavation in rock), site isolation or accessibility, or slope.

Table shows the costs estimated for site work associated with OSDS installation. Additional costs will be incurred for each system including permit fee ($100), engineering fees ($4,000), plumber connection fee ($500), and sometimes electrician connection fee ($500). Table shows the costs for equipment/materials for treatment and disposal options for systems sized for one to five bedrooms. The costs for ATUs are based on vendor quotes from Hawaii firms/reps: International Wastewater Technologies, OESIS, WaiponoPure, FujiClean and Presby for which there is a fairly large range for 1 bedroom to 5-bedroom sized units. We used reasonable values rather than only the least expensive and this gave values of $9,000 for 1BR to $15,000 for 5BR. Note, it is possible to get a small unit for $5000 and a 5BR size unit for $10,000, however, we assumed that not everyone will choose these least-cost options. The costs for septic tanks have a larger range of costs based on the material of construction. There are only two sizes for septic tanks 1,000 gallons (1-4BR) and 1,250 gallons (5BR). Concrete tanks range from $3,500-4,500, FRP tanks cost $2600-3,300, and some light plastic units can be purchased for around $1,500. However, the light units are not considered durable enough to last for 60 years as used in this study. We assumed a range of $3000 to $4,500 for these tanks.

Table 9 shows the total installed costs for each individual treatment and disposal system which includes equipment, additional fees, and site work. Table 2 (above) shows the annual operation and maintenance costs for the OSDS options as well as the replacement interval. Operation costs include electricity which is based on approximately 100W continuous draw and electricity cost of $0.35/kWh. Maintenance costs include annual pumping ($250) and inspection ($150). Systems must be completely replaced after either 30- or 60-years thus incurring the full installation cost again at that time. Table 10 shows the installed costs for each alternative combination of treatment and disposal systems. Table shows the total installation cost for Upcountry Maui for each alternative by summation of the cost for each TMK based upon the number of bedrooms. The data are arranged in lowest to highest capital cost which range from a low of $18 million to a high of $264 million. We calculated the net present cost (NPV) of initial installation, replacements in the future, and annual operation and maintenance of all the cesspool upgrades for a 60-year period (also in Table), in 2018 dollars. We used two discount factors reflecting the private cost of capital (5% home equity loan rate) and a rate reflective of public sector investment (2.8%) (OMB 2016). In both cases, we applied an annual inflation rate of 1.8% (based on Real GDP for Hawaii's economy, March 2017; dbedt.hawaii.gov). For the 2.8% discount rate, the NPV ranges from $22 million to $785 million. For the 5% discount rate, the range is from $20 million to $551 million.

For this project, we did not provide a range of costs for any systems or Alts, instead, we provide a single best estimate for the purchase/installation/operation/maintenance of each system under typical local conditions. Site-specific, non-standard conditions, such as locally poor soils, unknown underground utilities, undocumented structures, the need for removal of large trees, necessity to place systems in traffic bearing areas, contractor availability/scarcity, etc. could increase costs substantially. The amounts of these increases can be predicted only with detailed engineering analysis of each property, including site visits, records searches, soil tests, etc. that will be required for each property as part of the normal design/permitting process. It is estimated that costs could increase by up to 50% in the worst case. It is also possible that costs could decrease in the future as cesspool replacements ramp up to large numbers, additional contractors emerge, new technologies become common, and volume discounts become possible.

Cost Efficiency

We calculated the cost efficiency (CE; **Objective 6**, as the difference in nitrogen concentration from baseline (Benefit, B, in kg nitrate) divided by the cost of the upgrades (C, NPV in $USD2018) i.e. a modified Cost-Benefit Analysis, then ranked the options.

Equity

For objectives related to equity (**Objectives 7,8**), we evaluated equity within the Upcountry Maui community by calculating the number of households implicated in each alternative (which can be compared to the number of households in the entire community), and across the broader community of Maui by looking at the difference between the per annum costs borne by the Maui households for the alternative vs. the standard sewage fees a Maui household pays.

Costs Summary

Tables 7, 8, 9, and 10 present the costs calculated in this study. Several findings can be highlighted as follows:

- Sitework to install treatment systems costs about $6,000, and sitework to install a disposal system plus close/convert a cesspool costs about $4,000.
- Installed costs for septic tanks are $15,000-$17,000 and for ATUs are $22,000-$30,000 for 1BR - 5BR size units.
- Composting toilets cost $2,200 each, installed. The new nano/gates toilets are still several years away, however, it is likely that these toilets will be priced similar or possibly lower than composting toilets
- Installed costs for absorption disposal systems are $4,000 - $7,000 for 1BR - 5BR size systems (this assumes an average of 175 sf/BR).
- Drip irrigation disposal systems cost $8,000-$9000 and Evapotranspiration systems which are zero-discharge disposal systems cost $5,000-$9,000 for 1BR - 5BR size systems
- Installed costs for gray water systems are $4,000-$5000 for 1BR - 5BR size systems
- Total installed costs for treatment and disposal at a typical 3BR home depend on the type of system:
    - Septic tank-based systems where good N removal (>60%) is not required can cost $21,000 to $25,000.
    - The lowest cost package system ($16,000) is septic tank plus seepage pit which is suitable only where absorption is not feasible (due to slope, soil)
    - Septic tank-based systems with high N removal (80-98%) cost $25,000-$33,000.
    - ATU based systems mostly cost from $27,000 to $32,000, with two expensive systems that are over $40,000.
- Costs for installing the various upgrade alternatives in all 6,198 TMKs with cesspools (and thereby meeting the cesspool ban) range from $102M to $165M for septic tank-based systems and from $191M to $231M for ATU-based systems. The total

cost for upgrading to composting toilets is between these two ranges at $186M (these systems include replacing all toilets, adding a gray water system, and upgrading the cesspool to a seepage pit).

- Costs for several alternatives that do not upgrade all cesspools (do not meet ban) such as wellhead treatment, addition of sewers only in Pukalani/Makawao, and upgrading only the highest nitrogen emitters, are lower, ranging from $18M-$96M

Table 7 Cesspool upgrade site work cost estimate

Cost Item	ATU or Septic Tank	Absorption System	Cesspool Closure	Cesspool Conversion
Clearing and grubbing including small trees (landscaper) including haul away	1000	incl	0	0
Tree removal (larger trees) cut and hauk away and grind the stump ($1000+) per tree depending on size. Try to avoid.	0	0	0	0
Reseed grass and other replanting by landscaper	500	incl	0	0
Excavation and backfill: back hoe at $1500 per day w/operator and haul away excess, one day for tank plus one day for absorption system. If require mini excavator due to access issues, requires 4 days at $750 per day	1500	1500	750	0
Granualar bed/backfill material delivered at $20/cu yd	300	600	750	0
Shoring for excavation: Aluminum: $800-1500 per week delivered and picked-up	1000	0	0	0
Rebuild fence or wall: Wood or moss rock, 8 ft; $500 (carpenter) to $1500 for moss rock wall	750	incl	0	0
Vibrator for compaction: $100/day	150	150	0	0
Laborer to help with installation at $150/day	750	incl	0	0
Water for tank install: Use house water if can at $0; if water truck (1000 gal) at $1000	0	0	0	0
Cesspool pump out (500), cesspool clean (500), cesspool percolation test (1000)	0	0	500	2000
Total cost	**5950**	**2250**	**2000**	**2000**

Table 8 Costs for equipment/materials for OSDS treatment and disposal systems

	OSDS Treatment and Disposal Systems	Equipment and Materials				
		1BR	2BR	3BR	4BR	5BR
Treatment Options	ATU-N	$9,000	$9,000	$10,500	$12,000	$15,000
	ATU-N/DN	$10,500	$10,500	$12,000	$13,000	$17,000
	Septic Tank	$3,000	$3,500	$3,500	$4,500	$4,500
	Passive Biofilters (in-ground, medium, FL)	$8,600	$11,300	$12,500	$14,700	$15,900
	Passive Biofilters (in-ground, high, FL)	$11,100	$12,800	$14,000	$16,200	$17,400
	Composting toilets (also use for incinerating)	$2,200	$2,200	$4,400	$4,400	$6,600
Disposal Options	Absorption System (bed or trench)	$1,500	$2,200	$2,800	$3,400	$4,900
	Constructed Wetland	$4,000	$5,000	$6,000	$8,000	$10,000
	Disinfection	$1,000	$1,000	$1,000	$1,000	$1,000
	Drip Irrigation	$4,900	$5,000	$5,800	$5,900	$6,000
	Seepage Pit (new)	$6,400	$10,400	$14,400	$18,400	$22,400
	Evapotranspiration	$3,000	$4,000	$5,000	$6,000	$7,000
	NITREX ®	$5,800	$7,400	$8,200	$10,000	$10,800
	Presby Advanced Enviro-Septic & De-Nyte ®	$3,300	$4,700	$6,200	$7,700	$9,200
	Recirculating Sand Filter	$3,000	$3,000	$6,000	$6,000	$6,000
	Eliminite ®	$8,000	$8,000	$8,000	$8,000	$8,000
	Layered Soil Treatment System (MA)	$6,000	$6,000	$6,000	$6,000	$6,000
	Gray Water system	$1,600	$2,300	$2,300	$2,300	$2,300

Table 9 Total installed costs for individual OSDS treatment and disposal systems

	OSDS Treatment and Disposal Systems	Total Installed Cost including Fees				
		1BR	2BR	3BR	4BR	5BR
Treatment Options	ATU-N	$22,000	$22,000	$23,500	$25,000	$28,000
	ATU-N/DN	$23,500	$23,500	$25,000	$26,000	$30,000
	Septic Tank	$15,500	$16,000	$16,000	$17,000	$17,000
	Passive Biofilters (in-ground, medium, FL)	$21,100	$23,800	$25,000	$27,200	$28,400
	Passive Biofilters (in-ground, high, FL)	$24,100	$25,800	$27,000	$29,200	$30,400
	Composting toilets (also use for incinerating)	$2,800	$2,800	$5,600	$5,600	$8,400
Disposal Options	Absorption System (bed or trench)	$3,750	$4,450	$5,050	$5,650	$7,150
	Constructed Wetland	$6,250	$7,250	$8,250	$10,250	$12,250
	Disinfection	$2,000	$2,000	$2,000	$2,000	$2,000
	Drip Irrigation	$7,900	$8,000	$8,800	$8,900	$9,000
	Seepage Pit (new)	$8,650	$12,650	$16,650	$20,650	$24,650
	Evapotranspiration	$5,250	$6,250	$7,250	$8,250	$9,250
	NITREX ®	$8,050	$9,650	$10,450	$12,250	$13,050
	Presby Advanced Enviro-Septic & De-Nyte ®	$5,550	$6,950	$8,450	$9,950	$11,450
	Recirculating Sand Filter	$5,250	$5,250	$8,250	$8,250	$8,250
	Eliminite ®	$10,250	$10,250	$10,250	$10,250	$10,250
	Layered Soil Treatment System (MA)	$8,250	$8,250	$8,250	$8,250	$8,250
	Gray Water system	$4,100	$4,800	$4,800	$4,800	$4,800

Table 10 Total installed costs for treatment plus disposal systems for Alternatives 1-18

Alt	Description	1BR	2BR	3BR	4BR	5BR
Alt1	Septic Tank to Absorption System: 47% Reduction	$19,250	$20,450	$21,050	$22,650	$24,150
Alt2	Septic Tank to Constructed Wetland: 53% Reduction	$21,750	$23,250	$24,250	$27,250	$29,250
Alt3	Septic Tank to RSF to Drip Irrigation: 80% Reduction	$28,650	$29,250	$33,050	$34,150	$34,250
Alt4	Septic Tank to RSF to Seepage Pit: 47% Reduction	$20,750	$21,250	$24,250	$25,250	$25,250
Alt 4B	Septic Tank to Seepage Pit: 10% Reduction	$15,500	$16,000	$16,000	$17,000	$17,000
Alt5	Septic Tank to Eliminite to Absorption System: 80% Reduction	$29,500	$30,700	$31,300	$32,900	$34,400
Alt6	Septic Tank to Presby: 78% Reduction	$21,050	$22,950	$24,450	$26,950	$28,450
Alt7	Septic Tank to NITREX to Absorption System: 98% Reduction	$27,300	$30,100	$31,500	$34,900	$37,200
Alt8	Septic Tank to Recirculating Gravel Filter System to Absorption System: 84% Reduction	24500	25700	29300	30900	32400
Alt9	Septic Tank to "Layer Cake": 55% Reduction	$23,750	$24,250	$24,250	$25,250	$25,250
Alt10	Septic Tank to Lined/Sequence D/DN Biofilter: 91% Reduction	23750	24250	24250	25250	25250
Alt11	ATU-N to Absorption System: 53% Reduction	$25,750	$26,450	$28,550	$30,650	$35,150
Alt12	ATU-N/DN to Absorption System: 71% Reduction	$27,250	$27,950	$30,050	$31,650	$37,150
Alt13	ATU-N to Constructed Wetland: 58% Reduction	$28,250	$29,250	$31,750	$35,250	$40,250
Alt14	ATU-N to ET: 100% Reduction	$27,250	$28,250	$30,750	$33,250	$37,250
Alt15	ATU-N to Disinfection to Drip Irrigation: 82% Reduction	$31,900	$32,000	$34,300	$35,900	$39,000
Alt16	ATU-N/DN to Disinfection to Seepage Pit: 50% Reduction	$25,500	$25,500	$27,000	$28,000	$32,000
Alt17	Septic Tank to Passive FL Units (medium, in ground): 71% Reduction	$36,600	$39,800	$41,000	$44,200	$45,400
Alt18	Septic Tank to Passive FL Units (high) to Absorption System: 91% Reduction	$43,350	$46,250	$48,050	$51,850	$54,550

Table 11 Total installed cost and total net present value (NPV) for Alternatives 1 through 38, with ranking lowest-highest based on installed cost

Alt	Description	Total Installation Cost ($M)	Rank	NPV, 60 years, 2.8% Discount Factor ($M)	Rank	NPV, 60 years, 5% Discount Factor ($M)	Rank
35	Wellhead treatment (results same as base model)	$18.0	1	$38.8	2	$30.4	2
29-30-31	Sewer Pukalani only, no cesspool upgrades	$18.2	2	$22.1	1	$20.5	1
26-27-28	Sewer Makawao only, no cesspool upgrades	$55.6	3	$60.9	3	$58.7	3
19A	High impact: Septic Tank to Presby: 78% Reduction (highest mass reduction in alt 1-18)	$59.9	4	$118	5	$94.4	5
32-33-34	Sewer Makawao & Pukalani, no other upgrades	$73.9	5	$82.9	4	$79.3	4
19B	High Impact: ATU-N to ET: 100% Reduction (smallest area with >5 mg/L in alt 1-18)	$95.9	6	$250	9	$185	7
Alt4B	Septic Tank to Seepage Pit: 10% Reduction	$102	7	$221	6	$173	6
Alt1	Septic Tank to Absorption System: 47% Reduction	$124	8	$245	8	$196	8
23B-24B-25B	Sewer Pukalani, ST to Presby (highest mass reduction in alt 1-18) where possible	$133	9	$274	11	$242	11
Alt9	Septic Tank to "Layer Cake": 55% Reduction	$134	10	$329	13	$250	13
Alt10	Septic Tank to Lined/Sequence D/DN Biofilter: 91% Reduction	$134	11	$329	14	$250	14
Alt6	Septic Tank to Presby: 78% Reduction	$137	12	$278	12	$221	10
Alt2	Septic Tank to Constructed Wetland: 53% Reduction	$138	13	$348	15	$261	15
Alt4	Septic Tank to RSF to Seepage Pit: 47% Reduction	$147	14	$380	16	$285	16
Alt8	Septic Tank to Recirculating Gravel Filter System to Absorption System: 84% Reduction	$153	15	$410	19	$306	19
20-21-22	Sewer Makawao, ST to Presby (cheapest option)	$157	16	$274	10	$245	12
Alt5	Septic Tank to Eliminite to Absorption System: 80% Reduction	$162	17	$385	18	$293	18
Alt7	Septic Tank to NITREX to Absorption System: 98% Reduction	$165	18	$382	17	$292	17
36-37-38	Compost toilets, no effluent N	$186	19	$228	7	$210	9
Alt11	ATU-N to Absorption System: 53% Reduction	$191	20	$528	20	$385	20
Alt12	ATU-N/DN to Absorption System: 71% Reduction	$196	21	$538	21	$393	21
Alt16	ATU-N/DN to Disinfection to Seepage Pit: 50% Reduction	$196	21	$538	21	$393	21
Alt14	ATU-N to ET: 100% Reduction	$198	23	$560	24	$407	23
Alt13	ATU-N to Constructed Wetland: 58% Reduction	$204	24	$631	27	$450	27
Alt3	Septic Tank to RSF to Drip Irrigation: 80% Reduction	$213	25	$756	28	$531	28
23A-24A-25A	Sewer Pukalani, ATU-N to ET (smallest area with >5 mg/L in alt 1-18) where possible	$229	26	$584	26	$435	25
Alt15	ATU-N to Disinfection to Drip Irrigation: 82% Reduction	$231	27	$785	29	$551	29
Alt17	Septic Tank to Passive FL Units (medium, in ground): 71% Reduction	$236	28	$542	23	$415	24
Alt18	Septic Tank to Passive FL Units (high) to Absorption System: 91% Reduction	$264	29	$570	25	$443	26

Nitrogen Reduction with groundwater model

We obtained a DOH-developed baseline groundwater model (See Appendix IV: Groundwater Model) representative of nitrogen concentration in Upcountry Maui aquifers (aquifer nutrient loading). The purpose of the numerical groundwater flow and transport modeling was to test the consequences of the 38 cesspool conversion alternatives. The groundwater flow model that was used, MODFLOW 2005, is an international standard for simulating groundwater flow. A modular three-dimensional multi-species transport model, MT3DMS, was used to simulate movement of nitrogen due to groundwater flow. This groundwater model was used to calculate reductions in groundwater nitrate concentrations resulting from the reduction in nitrogen input for the 38 alternatives shown in Table 5, and these reductions were then evaluated with the **Objectives 3, 4, 5** in Table 1.

Baseline Groundwater Model Findings

A baseline model using a groundwater and transport model (Appendix IV) was prepared to represent existing nitrogen levels. The modeled area is larger than the Priority One area (**Error! Reference source not found.**) in order for more accurate simulations that are not influenced by boundary conditions. Table 12 shows the nitrogen inputs into the model; it includes the assumptions of 1.5 persons per bedroom, 70 gallons per person, and an N concentration of 87 mg/L. The total number of bedrooms in the study area is 30,750 and the subset of those that are on properties with cesspools are 22,908. The total nitrogen load from OSDSs is 1064.9 kg/day and the total flow rate is 3.23 million gallons per day (MGD) from all OSDSs, with 2.4 MGD and 793 kg-N/day coming from cesspools. These values just discussed are the baseline to which all the cesspool upgrade alternatives are compared, and they are based on the DOH model calibration to data collected from wells. We considered the effects of these assumptions by considering some higher and lower values. Table 12 also shows that if the load is calculated from the HAR 11-62 design standard (2 persons/BR and 100 gal/person), then the loads are almost double (1551 kg/d instead of 793 kg/d from cesspools) which could be a worst case for the existing level of development. However, the study area is not "built out" and additional properties could be developed which would add to the nitrogen load. The 2010 Census data indicates a study area population of 30,900, which is very close to an average of 1.0 persons per bedroom. Assuming that the 22, 908 bedrooms in TMKs with cesspools each have one person, the N concentration is 87 mg/L, and the average flow per person is 100 gal/d, then the cesspool load would be 756 kg/d which is pretty close to the "calibrated" model value (793 kg/d). This indicates that the calibrated model can be considered reasonable.

In the baseline model the highest underlying groundwater concentration in the modeled area is 13.8 mg/L (Table 14 and Figure 3). There are 8,972 acres with concentrations above 5 mg/L, and 991 acres with concentrations above 10 mg/L (Table 14 and Figure 4). Historical sugarcane and OSDSs contribute the majority (56%) of nitrate in the baseline model (Table 13 and Figure 5) while OSDSs contribute 33% (note: cesspools are 24.3% and other OSDSs are 8.7%).

Table 12 Nitrogen loading values used in the model

Alt4B	Persons/BR	Flow/person	N Conc	Bedrooms	Load kg/d
Baseline Total	1.5	70	87	30,750	1,064.9
Baseline Cesspools	1.5	70	87	22,908	793
Baseline Other	1.5	70	87		272
High Estimate Total	2	100	87	30,750	1,995.3
High Estimate Cesspools	2	100	87	22,908	1551
High Estimate Other	2	100	87		444
Low Estimate Total	1	70	87	30,750	698.4
Low Estimate Cesspools	1	70	87	22,908	529
Low Estimate Other	1	70	87		170
2010 Census Estimate Total	1	100	87	30,900	1,019.3
2010 Census Estimate Cesspools	1	100	87	22,908	756
2010 Census Estimate Other	1	100	87		263

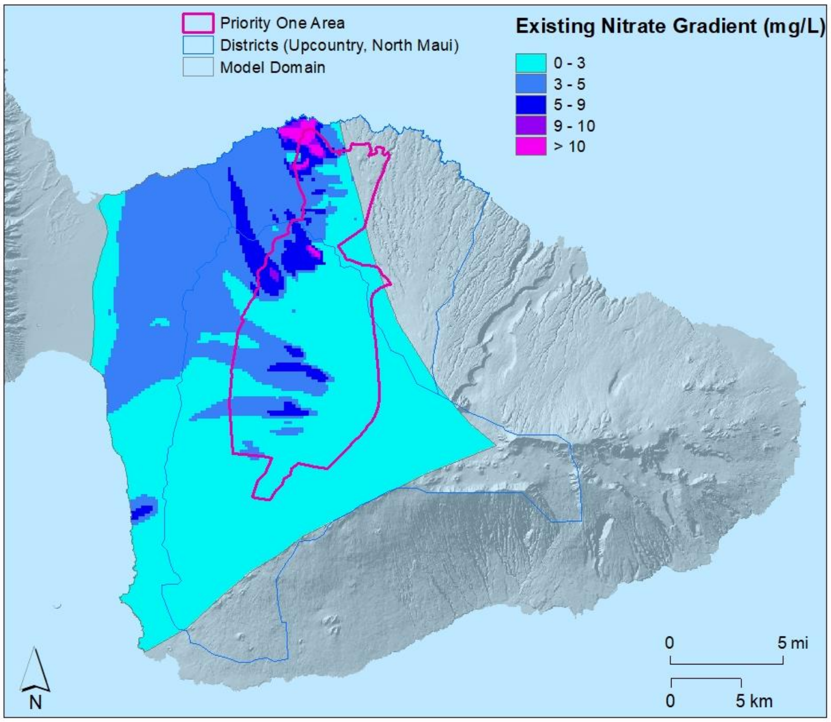

Figure 3. Map groundwater concentrations for baseline model

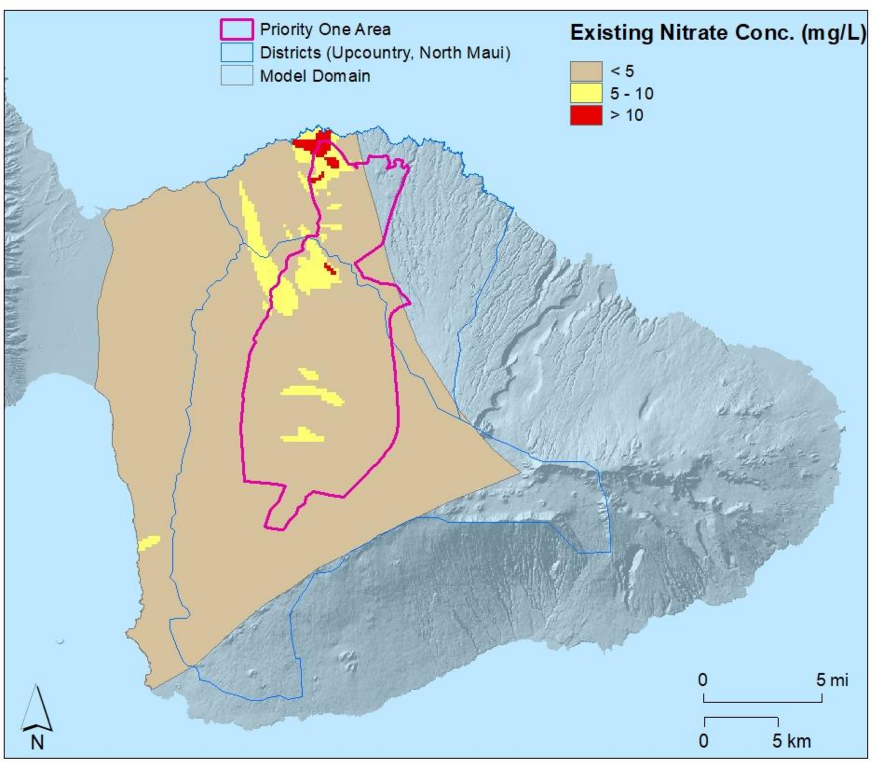

Figure 4. Areas above 5 and 10 mg/L in baseline model

Table 13. Summary of Base Groundwater Model Findings

Source	Mass Flux (kg/d)	Percent Flux
OSDS	1,064.8	33%
Historical Pineapple	67.2	2.1%
Historical Sugar Cane	1,813.9	56%
Pukalani Golf Course Recycle Water	3.5	0.11%
Golf Course (recycled water not applied)	7.8	0.24%
Haliimaile and Pukalani Wastewater Treatment Plant infiltration ponds/beds	19.1	0.59%
Natural/Background (including ranchlands)	287.5	8.8%
Total Flux	3,263.7	100

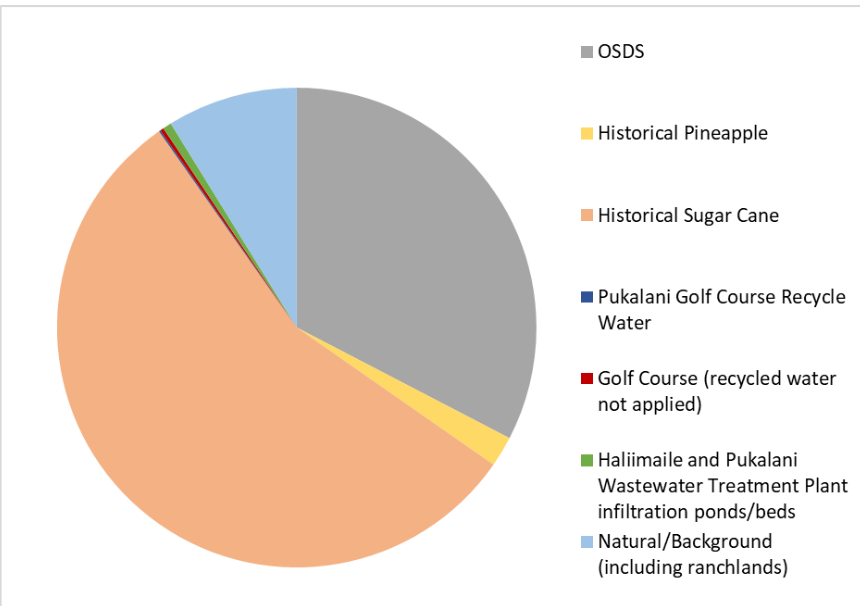

Figure 5. Pie Chart showing a summary of the contribution of each potential nitrate source across the entire area of study according to the baseline model

Groundwater Model Results for Upgrade Alternatives

Table 14 shows the modeled effects of the cesspool upgrade alternatives. For each alternative, it shows the baseline N load, the reduced load due to treatment, the amount of reduction (in kg and in %), the baseline maximum groundwater concentration, the reduced maximum groundwater concentration, and the areas with concentrations above 5 mg/L and 10 mg/L. Figures showing the areas affected for each alternative are shown in Appendix V (Figures AP5-1 through AP5-27). Several highlights can be described for the information in Table 14 and Figures AP5-1 to AP5-27 as follows:

- The status quo situation results in 991 acres of the study area having nitrate concentrations in excess of 10 mg/L, thus making wells in these areas unusable for drinking water unless treatment systems are installed. Adding wellhead treatment might sound easy, however, due to drinking water regulations, other area wells may also be required to provide treatment if they are part of the same “system.” Also, an additional nearly 8,000 acres would have groundwater with “high” nitrate levels between 5.0 and 9.9 mg/L.

- There are 6 alternatives which include septic tanks for treatment that eliminate the areas with >10 mg/L of nitrate (Alts 3, 7, 8, 10, 17, 18) and there are 6 which do not achieve this goal of keeping **all** of the groundwater safe for drinking purposes.
- All 6 of the ATU alternatives (Alts 11, 12, 13, 14, 15, 16) achieve the goal of keeping **all** of the groundwater safe for drinking purposes.
- The sewer-only alternatives for Makawao and Pukalani (Alts 26-34) do **not** significantly decrease the areas of unusable groundwater and essentially continue the status quo.
- The alternatives (Alts 19A and 19B) which only address the worst offenders (20% with highest N discharge) do not quite eliminate the areas >10 mg/L of nitrate, but they do reduce these areas by about 90% to between 109 to 129 acres. If the criteria were changed to the worst 25 or 30% offenders (exact value not determined in this study), then **all** of the groundwater could be improved to <10 mg/L of N.
- Composting toilets which could achieve zero-discharge of nitrogen to the groundwater would achieve the goal of keeping **all** of the groundwater safe for drinking purposes.

Step 7. Consider Trade-offs

The final step in the SDM process is to confront the trade-offs across all objectives and all alternatives. We facilitate this analysis by displaying results in a summarized strategy evaluation matrix (Table 15).

Table 14. Change in nitrate mass flux due to each alternative; and the areas with groundwater concentrations greater than 5 and 10 mg/L for each alternative

Alt #	Alternative	Mass Flux				Maximum Concentration			Areas	
		Baseline Mass Flux (kg/d)	Resulting Mass Flux (kg/d)	Delta Mass Flux	Mass Flux Reduction	Baseline Max Conc. (mg/L)	Modeled Alt. Max Conc. (mg/L)	Max Conc. Reduction	Area > 5 mg/L (acres)	Area > 10 mg/L (acres)
0	Baseline conditions with cesspools	1064.8	N/A	N/A	N/A	13.7	N/A	N/A	8,972	991
1	Septic Tank to Absorption System: 47% Reduction	1064.8	676.0	388.7	37%	13.7	11.3	17%	4,173	109
2	Septic Tank to Constructed Wetland: 53% Reduction	1064.8	648.1	416.6	39%	13.7	11.1	19%	3,764	76
3	Septic Tank to RSF to Drip Irrigation: 69% Reduction	1064.8	499.3	565.5	53%	13.7	7.8	43%	1,497	0
4	Septic Tank to RSF to Seepage Pit: 47% Reduction	1064.8	676.0	388.7	37%	13.7	11.3	17%	2,689	0
4B	Septic Tank to Seepage Pit: 10% Reduction (1.5 BR; 70 gal/person)	1064.8	1029.0	35.8	3%	13.7	12.7	7%	7,210	610
4B_HI	Septic Tank to Seepage Pit: 10% Reduction (2/BR; 100 gal/person)	1995.3	1823.3	172.0	9%	23.8	22.0	8%	26,237	4250
4B_LO	Septic Tank to Seepage Pit: 10% Reduction (1/BR; 70 gal/person)	698.4	638.2	60.2	9%	8.7	8.0	8%	1,813	0
4B_Census	Septic Tank to Seepage Pit: 10% Reduction (2010 census/no. BR; 100 gal/person)	1019.3	931.4	87.9	9%	12.4	11.5	8%	5,661	86
5	Septic Tank to Eliminite to Absorption System: 80% Reduction	1064.8	530.2	534.5	50%	13.7	10.1	26%	2,707	7
6	Septic Tank to Presby: 78% Reduction	1064.8	429.0	635.8	60%	13.7	10.2	26%	2,813	7
7	Septic Tank to NITREX to Absorption System: 98% Reduction	1064.8	447.9	616.8	58%	13.7	9.4	31%	1,912	0
8	Septic Tank to Recirculating Gravel Filter System to Absorption System: 84% Reduction	1064.8	513.8	551.0	52%	13.7	9.9	27%	2,547	0
9	Septic Tank to "Layer Cake": 55% Reduction	1064.8	640.2	424.6	40%	13.7	11.0	20%	3,706	68
10	Septic Tank to Lined/Sequence D/DN Biofilter: 91% Reduction	1064.8	480.7	584.0	55%	13.7	9.6	30%	2,183	0
11	ATU-N to Absorption System: 53% Reduction	1064.8	638.5	426.3	40%	13.7	9.1	33%	2,332	0
12	ATU-N/DN to Absorption System: 71% Reduction	1064.8	560.1	504.7	47%	13.7	8.5	38%	1,857	0
13	ATU-N to Constructed Wetland: 58% Reduction	1064.8	613.7	451.1	42%	13.7	8.9	35%	2,213	0
14	ATU-N to ET: 100% Reduction	1064.8	429.4	635.3	60%	13.7	7.8	43%	787	0
15	ATU-N to Disinfection to Drip Irrigation: 71% Reduction	1064.8	484.4	580.4	55%	13.7	7.8	43%	1,380	0
16	ATU-N/DN to Disinfection to Seepage Pit: 50% Reduction	1064.8	560.1	504.7	47%	13.7	8.5	38%	1,857	0
17	Passive FL Units (medium) to Absorption System: 71% Reduction	1064.8	560.1	504.7	47%	13.7	8.5	38%	1,857	0
18	Passive FL Units (high) to Absorption System: 91% Reduction	1064.8	468.6	596.1	56%	13.7	7.9	42%	1,048	0
19A	High impact: Septic Tank to Presby: 78% Reduction (highest mass reduction in alt 1-18)	1064.8	778.9	285.9	27%	13.7	11.8	14%	4,125	129
19B	High Impact: ATU-N to ET: 100% Reduction (smallest area with >5 mg/L in alt 1-18)	1064.8	780.6	284.1	27%	13.7	12.0	12%	4,051	109
20-21-22	Sewer Makawao, ST to Presby (cheapest option)	1064.8	352.0	712.8	67%	13.7	7.5	45%	817	0
23A-24A-25A	Sewer Pukalani, ATU-N to ET (smallest area with >5 mg/L in alt 1-18) where possible	1064.8	359.2	705.6	66%	13.7	7.8	43%	703	0
23B-24B-25B	Sewer Pukalani, ST to Presby (highest mass reduction in alt 1-18) where possible	1064.8	363.3	701.5	66%	13.7	7.5	45%	752	0
26-27-28	Sewer Makawao only, no cesspool upgrades	1064.8	842.4	222.3	21%	13.7	13.7	0%	7,139	926
29-30-31	Sewer Pukalani only, no cesspool upgrades	1064.8	898.3	166.5	16%	13.7	13.7	0%	6,238	991
32-33-34	Sewer Makawao & Pukalani, no other upgrades	1064.8	675.9	388.9	37%	13.7	13.7	0%	4,386	926
35	Wellhead treatment (results same as base model)	1064.8	1064.8	0.0	0%	13.7	13.7	0%	8,972	991
36-37-38	Compost toilets, no effluent N	1064.8	0.0	1064.8	100%	13.7	6.3	54%	2	0

Table 15. Strategy evaluation table. Each row represents an alternative, while each column is an objective. Each objective is color-coded with a 2 -point color gradient from yellow (worst), to green (best). QTY denotes the number of OSDS systems upgraded in each alternative.

	Objective Number -->	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7.**	**O8.**	**O9.**	**O10.**	**Policy Screen**
Alt #	Alternative	Alt Total Cost 2.8% DF	Cost per HH for 2.8%	Area > 10 mg/L (acres)	Mass Flux Reduction (%)	Area >5 mg/L (acres)	CE index (1=best)	% of total households (OSDS) in community affected	Diff from Maui mean ($/year)	Meets design criteria already?	Maintenance burden	Meets cesspool ban?
N/A	Base Model	NA	NA	991	37%	8972	NA	0%	NA	Yes, ALL	low	Yes
1	Septic Tank to Absorption System: 47% Reduction	$244,632,700	$39,470	109	39%	4173	0.21	52%	-290	Yes, ALL	low	Yes
2	Septic Tank to Constructed Wetland: 53% Reduction	$347,737,298	$56,105	76	53%	3764	0.16	52%	-114	Yes, ALL	moderate	Yes
3	Septic Tank to RSF to Drip Irrigation: 69% Reduction	$755,938,758	$121,965	0	37%	1497	0.10	52%	611	Yes, ALL	moderate	Yes
4	Septic Tank to RSF to Seepage Pit: 47% Reduction	$380,120,136	$61,329	0	50%	2689	0.14	52%	-51	Yes, ALL	moderate	Yes
4B	Septic Tank to Seepage Pit: 10% Reduction	$221,398,213	$35,721	610	60%	7210	0.02	52%	-350	Yes, ALL	low	Yes
5	Septic Tank to Eliminate to Absorption System: 80% Reduction	$385,017,741	$62,120	7	58%	2707	0.18	52%	-29	Yes, ALL	moderate	Yes
6	Septic Tank to Presby: 78% Reduction	$278,420,839	$44,921	7	52%	2813	0.30	52%	-221	Yes, ALL	low	Yes
7	Septic Tank to NITREX to Absorption System: 98% Reduction	$382,298,144	$61,681	0	40%	1912	0.21	52%	-30	Yes, ALL	low	Yes

	Objective Number -->	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7.**	**O8.**	**O9.**	**O10.**	**Policy Screen**
Alt #	Alternative	Alt Total Cost 2.8% DF	Cost per HH for 2.8%	Area > 10 mg/L (acres)	Mass Flux Reduction (%)	Area >5 mg/L (acres)	CE index (1=best)	% of total households (OSDS) in community affected	Diff from Maui mean ($/year)	Meets design criteria already?	Maintenance burden	Meets cesspool ban?
8	Septic Tank to Recirculating Gravel Filter System to Absorption System: 84% Reduction	$257,486,428	$41,543	0	55%	2547	0.28	52%	6	Yes, ALL	moderate	Yes
9	Septic Tank to "Layer Cake": 55% Reduction	$329,170,222	$53,109	68	40%	3706	0.17	52%	-143	Yes, ALL	low	Yes
10	Septic Tank to Lined/Sequence D/DN Biofilter: 91% Reduction	$194,802,972	$31,430	0	47%	2183	0.40	52%	-143	Yes, ALL	low	Yes
11	ATU-N to Absorption System: 53% Reduction	$528,144,567	$85,212	0	42%	2332	0.11	52%	219	Yes, ALL	high	Yes
12	ATU-N/DN to Absorption System: 71% Reduction	$538,108,994	$86,820	0	60%	1857	0.12	52%	241	Yes, ALL	high	Yes
13	ATU-N to Constructed Wetland: 58% Reduction	$631,249,165	$101,847	0	55%	2213	0.09	52%	395	Yes, ALL	high	Yes
14	ATU-N to ET: 100% Reduction	$560,110,309	$90,370	0	47%	787	0.15	52%	279	Yes, ALL	high	Yes
15	ATU-N to Disinfection to Drip Irrigation: 71% Reduction	$784,859,709	$126,631	0	47%	1380	0.10	52%	666	Yes, ALL	high	Yes
16	ATU-N/DN to Disinfection to Seepage Pit: 50% Reduction	$538,108,994	$86,820	0	56%	1857	0.12	52%	241	Yes, ALL	high	Yes
17	Passive FL Units (medium) to Absorption System: 71% Reduction	$541,943,660	$87,438	0	67%	1857	0.12	52%	299	Yes, ALL	low	Yes

	Objective Number -->	O1	O2	O3	O4	O5	O6	O7.	O8.	O9.	O10.	Policy Screen
Alt #	Alternative	Alt Total Cost 2.8% DF	Cost per HH for 2.8%	Area > 10 mg/L (acres)	Mass Flux Reduction (%)	Area >5 mg/L (acres)	CE index (1=best)	% of total households (OSDS) in community affected	Diff from Maui mean ($/year)	Meets design criteria already?	Maintenance burden	Meets cesspool ban?
18	Passive FL Units (high) to Absorption System: 91% Reduction	$570,130,010	$91,986	0	67%	1048	0.14	52%	374	Yes, ALL	moderate	Yes
19A	High impact: Septic Tank to Presby: 78% Reduction (highest mass reduction in alt 1-18)	$116,490,319	$63,344	129	67%	4125	0.33	15%	24	Yes, ALL	low	Yes
19B	High Impact: ATU-N to ET: 100% Reduction (smallest area with >5 mg/L in alt 1-18)	$250,244,508	$133,749	109	21%	4051	0.15	16%	832	Yes, ALL	high	Yes
20	Sewer Makawao, ST to Presby (cheapest option) where possible	$273,558,867	$45,284	0	21%	817	0.35	51%	-140	In theory, but major engineering required	low to homeowners, high to society	Yes
21	Sewer Makawao, ST to Presby (cheapest option) where possible	$273,558,867	$45,284	0	21%	817	0.35	51%	-140	In theory, but major engineering required	low to homeowners, high to society	Yes

	Objective Number -->	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7.**	**O8.**	**O9.**	**O10.**	**Policy Screen**
Alt #	Alternative	Alt Total Cost 2.8% DF	Cost per HH for 2.8%	Area > 10 mg/L (acres)	Mass Flux Reduction (%)	Area >5 mg/L (acres)	CE index (1=best)	% of total households (OSDS) in community affected	Diff from Maui mean ($/year)	Meets design criteria already?	Maintenance burden	Meets cesspool ban?
22	Sewer Makawao, ST to Presby (cheapest option) where possible	$273,558,867	$45,284	0	16%	817	0.35	51%	-140	In theory, but major engineering required	low to homeowners, high to society	Yes
23A	Sewer Pukalani, ATU-N to ET (smallest area with >5 mg/L in alt 1-18) where possible	$584,279,863	$96,719	0	16%	703	0.16	51%	384	In theory, but major engineering required	high	Yes
24A	Sewer Pukalani, ATU-N to ET (smallest area with >5 mg/L in alt 1-18) where possible	$584,279,863	$96,719	0	16%	703	0.16	51%	384	In theory, but major engineering required	high	Yes
25A	Sewer Pukalani, ATU-N to ET (smallest area with >5 mg/L in alt 1-18) where possible	$584,279,863	$96,719	0	37%	703	0.16	51%	384	In theory, but major engineering required	high	Yes

	Objective Number -->	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7.**	**O8.**	**O9.**	**O10.**	**Policy Screen**
Alt #	Alternative	Alt Total Cost 2.8% DF	Cost per HH for 2.8%	Area > 10 mg/L (acres)	Mass Flux Reduction (%)	Area >5 mg/L (acres)	CE index (1=best)	% of total households (OSDS) in community affected	Diff from Maui mean ($/year)	Meets design criteria already?	Maintenance burden	Meets cesspool ban?
23B	Sewer Pukalani, ST to Presby (highest mass reduction in alt 1-18) where possible	$274,004,340	$45,357	0	37%	752	0.34	51%	-149	In theory, but major engineering required	low to homeowners, high to society	Yes
24B	Sewer Pukalani, ST to Presby (highest mass reduction in alt 1-18) where possible	$274,004,340	$45,357	0	37%	752	0.34	51%	-149	In theory, but major engineering required	low to homeowners, high to society	Yes
25B	Sewer Pukalani, ST to Presby (highest mass reduction in alt 1-18) where possible	$274,004,340	$45,357	0	0%	752	0.34	51%	-149	In theory, but major engineering required	low to homeowners, high to society	Yes
26	Sewer Makawao only, no cesspool upgrades elsewhere	$60,854,128	$35,546	926	100%	7139	0.48	14%	-244	In theory, but major engineering required	low to homeowners, high to society	In sewered area

	Objective Number -->	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7.**	**O8.**	**O9.**	**O10.**	**Policy Screen**
Alt #	Alternative	Alt Total Cost 2.8% DF	Cost per HH for 2.8%	Area > 10 mg/L (acres)	Mass Flux Reduction (%)	Area >5 mg/L (acres)	CE index (1=best)	% of total households (OSDS) in community affected	Diff from Maui mean ($/year)	Meets design criteria already?	Maintenance burden	Meets cesspool ban?
27	Sewer Makawao only, no cesspool upgrades elsewhere	$60,854,128	$35,546	926	100%	7139	0.48	14%	-244	In theory, but major engineering required	low to homeowners, high to society	In sewered area
28	Sewer Makawao only, no cesspool upgrades elsewhere	$60,854,128	$35,546	926	100%	7139	0.48	14%	-244	In theory, but major engineering required	low to homeowners, high to society	In sewered area
29	Sewer Pukalani only, no cesspool upgrades elsewhere	$22,089,239	$18,151	991	NA	6238	1.00	10%	-535	In theory, but major engineering required	low to homeowners, high to society	In sewered area
30	Sewer Pukalani only, no cesspool upgrades elsewhere	$22,089,239	$18,151	991	NA	6238	1.00	10%	-535	In theory, but major engineering required	low to homeowners, high to society	In sewered area

	Objective Number -->	O1	O2	O3	O4	O5	O6	O7.	O8.	O9.	O10.	Policy Screen
Alt #	Alternative	Alt Total Cost 2.8% DF	Cost per HH for 2.8%	Area > 10 mg/L (acres)	Mass Flux Reduction (%)	Area >5 mg/L (acres)	CE index (1=best)	% of total households (OSDS) in community affected	Diff from Maui mean ($/year)	Meets design criteria already?	Maintenance burden	Meets cesspool ban?
31	Sewer Pukalani only, no cesspool upgrades elsewhere	$22,089,239	$18,151	991	27%	6238	1.00	10%	-535	In theory, but major engineering required	low to homeowners, high to society	In sewered area
32	Sewer Makawao and Pukalani, no cesspool upgrades elsewhere	$82,943,366	$28,318	926	27%	4386	0.62	24%	-365	In theory, but major engineering required	low to homeowners, high to society	In sewered area
33	Sewer Makawao and Pukalani, no cesspool upgrades elsewhere	$82,943,366	$28,318	926	66%	4386	0.62	24%	-365	In theory, but major engineering required	low to homeowners, high to society	In sewered area
34	Sewer Makawao and Pukalani, no cesspool upgrades elsewhere	$82,943,366	$28,318	926	66%	4386	0.62	24%	-365	In theory, but major engineering required	low to homeowners, high to society	In sewered area

	Objective Number -->	O1	O2	O3	O4	O5	O6	O7.	O8.	O9.	O10.	Policy Screen
Alt #	Alternative	Alt Total Cost 2.8% DF	Cost per HH for 2.8%	Area > 10 mg/L (acres)	Mass Flux Reduction (%)	Area >5 mg/L (acres)	CE index (1=best)	% of total households (OSDS) in community affected	Diff from Maui mean ($/year)	Meets design criteria already?	Maintenance burden	Meets cesspool ban?
35	Wellhead treatment (results same as base model)	$38,842,349	$0	991	66%	8972	0.00	0%	NA	Yes	low to homeowners, high to society	No
36	Compost toilets, no effluent N	$227,927,752	$27,441	0	66%	2	0.62	69%	-395	No	high	No
37	Compost toilets, no effluent N	$227,927,752	$27,441	0	66%	2	0.62	69%	-395	No	high	No
38	Compost toilets, no effluent N	$227,927,752	$27,441	0	66%	2	0.62	69%	-395	No	high	No

Interpretation of results

The aim of this research was to use evidence to help design nutrient pollution solutions that will reduce the most pollution at the least cost, while considering equity. We identified and compared alternatives including various types of cesspool upgrades and installation of sewers. To achieve the largest pollution reduction possible at the lowest cost, we examined (i) how alternative management practices may influence groundwater nitrogen levels and at what cost; and (ii) where nutrient reductions would be most beneficial to meet both water quality regulations/objectives, and other social goals. We interpret the results of the analysis and provide specific recommendations below.

Comparison across objectives.

As illustrated in the Strategy Evaluation Table (Table5), some alternatives perform better at each one of the individual objectives:

1 Cost.

The 60-year NPV is lowest for the partial sewering Pukalani only alternative ($22.1 million at 2.8% discount rate), followed by wellhead treatment ($38.8 million), sewering Makawao ($60.9 million) and sewering both. The lowest cost partial sewering and wellhead treatment alternatives do not perform well in terms of other objectives, and do not meet the cesspool ban. Adding cesspool upgrades to these partial sewering projects raised the total cost by 300% (e.g., $274 million combined for Pukalani or Makawao partial sewering with septic tanks + Presby disposal). Upgrading the worst offenders to a septic tank to Presby or ATU-N to ET are the least expensive of the upgrade-only alternatives (A19A and 19B, $118/$250 million, which target the worst 20% of polluters). The least expensive alternatives that upgrade all the cesspools are Alt4B (septic tanks to seepage pits, $221 million), Alt1 (septic tanks to absorption beds, $245 million), Alt6 (septic tank to Presby, $274 million), Alt9 and Alt10 (septic tank to layer cake or lined sequence DN biofilter, both are $329 million). Alternatives that include ATUs are all over $500 million because these systems have power requirements, greater maintenance requirements, and have lifespans of 30 years (unlike septic tanks with 60-yr life), thus requiring the expense of a replacement during the 60-yr analysis period. Applying a higher discount rate does not change the relative ranking of the alternatives, although the costs are slightly lower in most cases.

2 Cost per household.

Least cost per household are the partial sewering only with upgrading of other cesspools ($18-35.5k; A26-34), and the composting toilets ($27k; A36-38) alternatives. Partial sewering plus low cost option (septic tank plus Presby) is about $45k, and advanced option (ATU-N to ET) runs about $100k (A20-25). Targeting the worst polluters (A19A, B) would cost the households $63-133k, depending on the system choice. The range of per household cost for the various individual alternatives (A1-18) is $31-133k over the 60-year time horizon.

3 Drinking water standard.

The nitrate-N standard of <10 mg/l is not achieved in several alternatives, including the partial sewering Makawao and Pukalani with no conversion for the other cesspools (A26-35) (when nearly 1,000 acres will be above the 10 mg/l standard), the alternatives that just address the 20% worst emitters (Alt19A/19B) which leave 109-129 acres above the standard, as well as some of the lowest cost alternatives that replace all cesspools (Alt4B, Alt1, Alt2, Alt9, and two others that are very close Alt5 and Alt6). Alternatives that do meet the drinking water standard for the entire area and also meet the cesspool ban include Alt3, Alt7, Alt8, and Alt10-Alt18, which are the more expensive alternatives with ATUs.

4 Flux reduction.

Max flux reduction was highest with compost toilets (A36-38), but would require a blackwater system for kitchen sink waste and change in laws. Partially sewering Makawao and Pukalani with no cesspool upgrades elsewhere (A32-34) results in 37% reduction in flux; partially sewering Makawao or Pukalani and converting all other cesspools to either ATU or septic results in 66-67% reduction in flux (A20-25). Looking at individual solutions, some achieve slightly lower results, e.g., ST + Presby (60%; A6), ST to NITREX to absorption system (58%; A7), ATU-N to ET (60%; A14).

5 Risk.

The area that is >5mg/l is lowest in the options that partially sewer Pukalani <u>and</u> convert cesspools to ATU-N + ET or Septic tank + Presby elsewhere (703 and 752 acres remain above 5mg/l; A23-25); similar results are obtained if partially sewering Makawao coupled with septic tank to Presby everywhere where possible (A20-22), or convert all cesspools to ATU-N with ET (787; A14). All the other individual alternatives leave much larger areas contaminated (1,000 to 4,000 acres).

6 Cost efficiency.

(B/C, or N flux reduction per dollar spent over 60 years). Rank of the highest bang for buck is (1) partially sewering only Pukalani (A29-31), (2) partially sewering Makawao and Pukalani (A32-34), then (3) partially sewering only Makawao (A26-28), all with no cesspool upgrades anywhere. The most cost-efficient option amongst those that address (most) cesspools is septic tank to Presby (19A). Notably, wellhead treatment has zero cost-efficiency because it delivers no environmental benefit to the fundamental objective of reducing nitrogen flux to the aquifer.

7 Equity – Community.

Why should I have to pay if I am not the problem? From one perspective, equity can be considered to be that the cost is borne by those who are the most egregious emitters, and thus the fewest people bear the cost for reducing nitrogen. Alternatives 19A and B – where only the

20% worst emitters of effluent, and the sewer alternatives without additional upgrades, affect the fewest people.

Why should I have to pay when my neighbors aren't? Equity could also be considered as the number of households implicated in each alternative, where a higher number would spread the cost across more of the community. There are quite a few options where nearly everyone is involved.

8 Equity – Maui wide.

Why should I have to pay more than other people on Maui for my household waste disposal? The average annual cost of sewer fees paid by other residents of Maui is $816 per household. The cost to individual households from the alternatives considered would be $240-535 below this average (for the sewering only alternatives), $395 less (composting), and $300 less - $6 more (individual septic systems). However, ATUs, passive units, combined sewer-ATU alternatives can cost from $220 more up to double what the average household spends on waste disposal over the 60-year time horizon.

9 Design standards.

Only a few of the alternatives have existing design standards for wastewater treatment and disposal systems including alternatives 1, 6, 11, 12, 16, 19A/B, 20-21-22, 23B-34. Some of the other alternatives do not have design standards, but can be approved without them including wetlands, drip irrigation, and ET systems. The other systems do not have design standards, which will require the state to develop design standards before they can be approved and installed (Alts 5, 7, 8, 9, 10, 17, 18). This represents a time delay and likely additional costs. Wellhead treatment does not address the cesspool issue at all; sewering would require major engineering.

10 Maintenance burden.

The lowest maintenance burden is associated with some of the septic tank options. The partial sewering options (with no cesspool upgrades) pose a low maintenance burden to the homeowners once they are hooked up, but transfers this burden to society through the required operation and maintenance of the centralized system.

A comment on the cesspool ban.

Alternatives 1-25 meet the cesspool ban, however, options 26-34 only meet the ban in the sewered areas, and the wellhead treatment does not meet the ban. The composting toilets may meet the ban, if the cesspools are decommissioned or turned into seepage pits for kitchen sink water only (which would require changes in current regulations).

Towards decisions about alternatives

The final decision-making power is in the hands of landowners, the state legislature, and DOH, not the decision analysts. The approach taken in this study can support more transparent decision-making by clearly identifying objectives, how each alternative performs, and trade-offs, but the ultimate decisions rely on normative judgments that are the responsibility of public officials. The next step towards making a decision is to decide which objectives are most important, and how much the achievement of certain objectives can be given up in order to achieve other objectives. This normative weighting of objectives is beyond the scope of this analysis. Notably, there are techniques in decision science to elicit weights to make some objectives more important, which may be something the DOH wants to engage in as they move forward. That said, we are able to pull out some highlights and present a few illustrative scenarios where there are key trade-offs.

Table 15 is called a strategy evaluation table and it is designed to serve as a decision aid. The color scheme in Table 15 helps identify alternatives that perform well across many objectives (lots of green), or poorly (lots of yellow). A mix of colors illustrates trade-offs across objectives presented by a given alternative. The table can be used to evaluate individual alternatives, or compare across alternatives.

The first cut can be alternatives that perform poorly across multiple objectives (many yellow cells), and should thus not be considered – such as well-head treatment (Alt 35), which fails to decrease groundwater risk, and consequently also has zero cost-effectiveness.

We can highlight some alternatives that seem to be winners (i.e., they meet most objectives, illustrated by lots of green). The strategy evaluation table (reveals an obvious winner, composting toilets, which meets the fundamental objectives of reducing cost, impact, and risk, while ensuring equity, but it does not meet the cesspool ban nor comply with current regulations. There are also significant technical and social hurdles to overcome, which we did not address in this analysis. We discuss these in our recommendations section.

A number of septic tank alternatives (Alt 6, 8, 10, 19A) perform well across multiple objectives, as do the sewering Makawao (or Pukalani) combined with septic tank to Presby where possible alternatives (Alt 20-22, 23B-25B). The key difference between these alternatives is the risk of exceeding 5 and 10mg/l nitrate standards, which is quite a bit higher in the former. This may or not be an acceptable risk. The sewering plus upgrade alternatives (Alt 20-25) all eliminate the area at risk of >10mg/L, but leave 700-800 acres susceptible to >5mg/L. All these alternatives will cost around $250 million to install, operate, and maintain for the next 60 years. Notably, in the sewering alternatives, more advanced upgrades to the cesspools outside the sewage area (Alt 20-22 upgrade cesspools with the cheapest option where possible) do not deliver much additional benefit, but cost quite a bit more. And alternatives that only sewer the neighborhoods without attending to the cesspools at all are the cheapest alternatives, both overall and per household, but they result in potentially unacceptable risk to aquifers, low flux reduction benefits, and do not meet the ban.

If decision makers are hoping to get the most nitrogen reduction benefit per dollar spent, then sewering Pukalani with no cesspool upgrades elsewhere are the best alternatives (Alt 29-31), but as the yellow cells indicate, the area at risk of being >5mg/L or >10mg/L nitrate is quite high (~6000 and ~1000 acres, respectively), it does not meet the ban, the mass flux reduction is quite low (16%), and only a small number (10%) of households in the area would be participating in the solution, although the cost per affected household would be quite low ($18k). This would also be the selection if decision makers want the cheapest solution.

If decision makers cannot allow any area to reach >10mg/l, then many alternatives are eliminated. The lowest cost alternative to meet the 10mg/l standard will cost $227 million over the 60-year project timeframe. Relatively low-cost septic tank-based alternatives (8, 10) meet this standard, at a much cheaper cost per household than the sewering alternatives (Alt 20-25), which have similar overall costs. Another benefit of the septic-based alternatives is more households in the community participate (increasing equity), though the sewering alternatives reduce nitrogen flux more.

Only composting toilets (at $228million) will ensure that all the area meets the more strict 5mg/l standards; the next best will restrict exceedance to 703 acres at a cost of $584million (Alt 23A-25A sewering Pukalani and installing ATUs with ET where possible), or 752 acres at a cost of $274million (Alt 23B-25B sewering Pukalani and installing septic tank to Presby where possible). All of these alternatives meet the cesspool ban.

Alternatives that target the TMKs with the highest nitrogen contributions (Alt 19A and 19B) would cost $116 and $250 million, but the additional cost for 19B does not buy much result. 19B is far less cost-effective than 19A. Both these alternatives reduce the area at risk of over 10mg/L to about 100 acres, and only affect ~15% of households, which may be perceived as attractive or inequitable, depending on the perspective. These alternatives meet the cesspool ban.

Notably, most alternatives will cost less per annum over the lifetime of the upgrade than other Maui residents pay. Some of the sewering alternatives would have the Upcountry households paying about $500/year less than the average wastewater disposal cost, though others are $400/year more. This offers a potential opportunity for cost recovery by charging residents across the county equally for municipal wastewater services. Some alternatives have residents paying similar costs as the average Maui household (Alt 7-8), while others would have them pay far more.

Recommendations

General

Aquifers that are designated as potable should be maintained in that state and preserved for current and future use to the extent that is feasible via source control. In the case of Upcountry Maui, the only feasibly controllable source is OSDSs, which constitute approximately one third of the total nitrogen inputs which includes cesspools (24%). Cesspool upgrade alternatives that preserve the groundwater for potable use are those that minimally provide nitrate-N concentrations <10 mg/L for 100% of the land area. This results in a subset of acceptable alternatives. Some DoH reports aim to maintain all groundwater nitrate-N concentrations below 5 mg/L. Notably, because the non-cesspool sources are very large, no alternatives evaluated here, even zero-discharge, can achieve that objective.

Further investigations

We recommend to investigate inputs of chloramine into drinking water and thus emissions via cesspools, and, if appropriate, incorporate it into the groundwater model.

Small cluster sewer systems were not investigated in this study because they require a more involved design process that is too expensive and time consuming for this project and would normally be done by a professional A/E design firm. The process would include dividing up neighborhoods into drainage sub-basins, predicting flows, finding land to locate treatment and disposal facilities, and establishing mini sewer districts to collect fees, procure easements, procure operator services, apply for and maintain government permits, etc. It is recommended that such a study be conducted as there are examples of such system solutions on the mainland. It is also recommended to investigate the cost of centralized sewering of the entire community including a WWTP and a disposal system.

We recommend to pilot study and then develop design standards for passive denitrifying absorption systems (Alts 9, 10, 17, 18) as well as pilot study of Nitrex and Eliminite and Presby (with De-nyte) for the same purpose.

We recommend to extend the study of alternatives 19A/B to determine how many more TMKs would have to be included (in addition to the worst 20%) to achieve zero acres of >10mg/L nitrate and to find the cost.

We recommend to conduct composting toilet study, including literature, current practice data from mainland, and pilot studies in Hawaii to gain familiarity, experience maintenance issues, determine pathogen risks in compost, acceptable handling practices, and develop regulatory standards including permitting and maintenance requirements.

Program management and efficiency

We recommend resources be dedicated to program management, as upgrading 88,000 cesspools will require each to go through the approval process which includes review and approval of test data and design submittals from engineers, and keeping of records. This will be a huge task that would require several additional staff. In addition, it will become even more important for the DOH to implement a more comprehensive life-cycle type management program for OSDSs. We recommend to determine a framework and the required DOH staffing to regulate all the OSDSs including upgraded cesspools in order to ensure public health is protected in the state.

We recommend to develop design standards for drip irrigation systems and ET systems to make approval of such systems routine instead of one-off design for each property as is the current situation.

Financing

We recommend to investigate financing options for completing any alternative program of upgrades. Every effort should be made to capitalize on economies of scale. Financing options would include individual homeowner pays, state/federal grants, state tax credits, privatization of individual systems similar to rooftop solar systems, County owning/operating all individual systems, Community association formation followed by assessment for capital costs and billing of O&M costs, public-private partnerships, and other options.

Legislation and administrative actions

Based on the investigations recommended above, write legislation to facilitate gray water, composting toilets, drip irrigation, ET systems, passive denitrifying absorption systems, program management including issuing OSDS permits and associated requirements, and financing methods. Composting toilets in fact achieve the fundamental objective of reducing nitrogen pollution to the groundwater, but do not comply with current regulations. Composting toilets also would require homeowners to take an active and regular role in their own sewage treatment (clean bulking agent has to be added to the units regularly and dirty compost removed and discarded with refuse) which may not be realistic on a large scale. Depending on the cost of the future “Gates” toilets (not yet on the market and no cost data available), which function the same as the composting toilets yet require less homeowner maintenance, this may become an important option to consider and allow by law.

One concern about exclusively relying on the ban to control cesspools is that it does not specify what technologies to use, instead, as our analysis highlight, most homeowners will have multiple options, each with its own costs and nitrogen removal efficiencies. Criteria are needed to guide homeowner choices to ensure that sufficient nitrogen is removed, such that cumulatively all groundwater is maintained with <10mg/l of nitrate. We therefore strongly recommend that DoH develop such criteria.

The cesspool ban has regulatory efficiency, and proffers a mechanism for the DoH to engage with all homeowners in any funding and technical assistance. While on its face the ban seems equitable as all homeowners have to comply equally, there may be solutions that have greater economic efficiency and/or environmental benefits that better achieve the fundamental objective of the ban (i.e., cost-effectively reducing nitrogen inputs into drinking water sources and sensitive waters). For example, our analysis revealed that the objective of 10mg/l can be achieved by targeting only certain areas and/or certain cesspools. This suggests that a systems perspective would improve outcomes, i.e., when the fundamental objective can be met by intervening in part of the system, these areas are targeted and exemptions to the ban might be considered for remaining households.

Any solution that differentially impacts some homeowners would raise equity concerns. Indeed, in some scenarios, some homeowners might be faced with installing an even more expensive system than they would have if they were just responsible for upgrading individually, because the more elaborate system would remove much more nitrogen and thereby achieve system goals more efficiently. Any system-scale solution would, of course, require subsidizing homeowners who upgrade. We recommend that DoH adopt a systems perspective, and design collective solutions and creative funding mechanisms to improve the economic efficiency.

Conclusions

The project achieved all objectives, namely, it: 1) identified a suite of cesspool replacement options, 2) developed a range of management alternatives to upgrade cesspools that incorporate feasibility, 3) analyzed environmental benefit of each alternative; 4) enumerated costs of the alternatives; and 5) provided recommendations on the alternatives relative to cost, environmental benefit, and stakeholder-identified objectives. The approach to evaluate the utility of proposed actions via a participatory and structured decision making process was successful in engaging a diverse set of stakeholders over a sustained period, bringing agency officials, academic experts, and the public together to integrate social values and science. As such, the project achieved its strategic goals to build a framework for academic-agency collaboration, and to pilot a collaborative decision-making framework with communities. The project team hopes that this framework will provide pay-offs for agency decision making far into the future, leading to decisions that are more transparent, robust, and publicly accepted. We recommend committing to a participatory and structured decision making process for future environmental problems.

Stakeholders strongly challenged the prioritization of Upcountry Maui cesspools. The 2017 report spurred strong public pushback, and subsequent response to comments published by DoH only addressed some of the concerns. This project tried to handle these objections by highlighting concerns that the stakeholders raised in various sections throughout the report. That said, most were outside the scope of this analysis. We recommend continuing a good faith process of responding to stakeholder concerns and claims with science, where appropriate, and open communication. We understand that the DoH is constrained by legal mandate, but we furthermore recommend that, insofar as it is possible, future prioritization processes follow the structured decision-making framework piloted here. We believe this would lead to more economically efficient, equitable, and socially acceptable outcomes.

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Appendix I: Stakeholder group

Table S1. Stakeholder group

Stakeholders	Department/Agency/Company	Title/Position
Agawa, Shayne	Maui Dept. of Environmental Mgmt	Deputy Director
Baisa, Gladys	formerly Maui County Water Supply	former Director
Baltizar, Brendan		Farmer
Blumenstein, Eva	Maui Dept. of Water Supply	Planning Director
Coleman, Stuart	Surfrider	HI Islands Manager
Jacintho, William	Maui Cattlemen's Association	President
Kau, Helene	Maui County Water Supply	Deputy Director
Mayer, Dick	UH Maui, Retired	Economics Professor
Meidell, Scott	Real Estate and Land Management	Senior Vice President
Nakagawa, Eric	Maui Dept. of Environmental Mgmt	Division Chief
Nakahata, Mae	HC&S/A&B	Farmer
Niles, Annette	Maui Cattlemen's Association	Rancher
Nishoka, Miles	Hawaii Dept. of Health	Cesspool Coordinator
O'Keefe, Sean	HC&S	Environmental Manager
Pang, Lorrin	Hawaii Dept. of Health	Maui District Health Officer
Pearson, Jeff	Maui County Water Supply	Director
Pruder, Sina	Hawaii Dept. of Health	Chief, Wastewater Branch
Reynolds, Christin	One World One Water	Water advocate
Seto, Joanna	Hawaii Dept. of Health	Chief, Safe Drinking Water Branch
Strand, Darren	A&B	Pineapple
Sugimura, Yukilei	Maui County Council	Councilmember
Thompson, Theresa	Maui Cattlemen's Association	Rancher
Thomson, Richelle	Maui County	Corporation Counsel
Uehara, Norris	Hawaii Dept. of Health	Pollution Prevention Section Supervisor
Watanabe, Warren		Farmer

Appendix II: Options

1. Introduction

This Appendix describes the treatment and disposal technologies that are considered in the main report. The following sections are summarized from the "Onsite Wastewater Treatment Survey and Assessment" report (Water Resources Research Center and Engineering Solutions, Inc., 2008). Therefore, citations of the material are not repeated throughout. For more details, please reference the report.

2. Importance of Nitrification and Denitrification

The main pollutant of concern from sewage dispersed on-site is the fully oxidized form of nitrogen (nitrate, NO_3^-) because it is high mobile in the subsurface (does not sorb). Thus it readily travels to underlying groundwater. Nitrogen in raw wastewater is present as a combination of organic-bound N and ammonia (reduced forms). These are converted aerobically via ammonification (Org-N -> NH_3) and then nitrification converts the NH_3 into nitrate. In order to remove nitrate from the water, denitrification is required – which converts nitrate into nitrogen gas which is released to the atmosphere and is inert (non-GHG).

3. Wastewater Treatment Methods

The following describes various on-site wastewater treatment methods that have been reviewed for adaptability in Upcountry Maui. These technologies convert household wastewater constituents into endproducts which then must be disposed into the ground via a separate disposal system. Section 3, describes the TREATMENT methods and Section 4 describes the DISPOSAL methods.

3.1. Aerobic Treatment Unit-w/Nitrification

An aerobic treatment unit (ATU) is an individual wastewater system that is designed to retain solids, aerobically decompose organic matter over time, and allow effluent to discharge into an approved disposal system. There are many types of ATUs, and the following will describe the most commonly used: suspended-growth flow-through ATUs and combined attached and suspended growth ATUs. ATUs also typically include primary treatment plus biological secondary treatment in different compartments. These units typically include nitrification.

3.1.1. Suspended-Growth Flow-Through ATU w/Nitrification

A suspended-growth flow-through ATU is a biological treatment system where microorganisms are kept in suspension by mixing air with wastewater influent and concentrated underflow or sludge (from a clarifier) in an aeration tank (Figure AP2-1). If there is no integral primary settling basin, a separate septic tank or pre-loader should be installed upstream of the ATU. The purpose of this additional tank is to remove readily settleable solids and floating matter that will reduce suspended solids loading.

From the aeration tank, the mixture is passed into a secondary clarifier, where microorganisms settle to the bottom, forming a layer of sludge. The clarified liquid effluent is passed to a disposal system. Some of the sludge solids in the settling basin will decompose, while the remainder accumulates and must periodically be removed (pumped out) and properly/legally disposed of offsite.

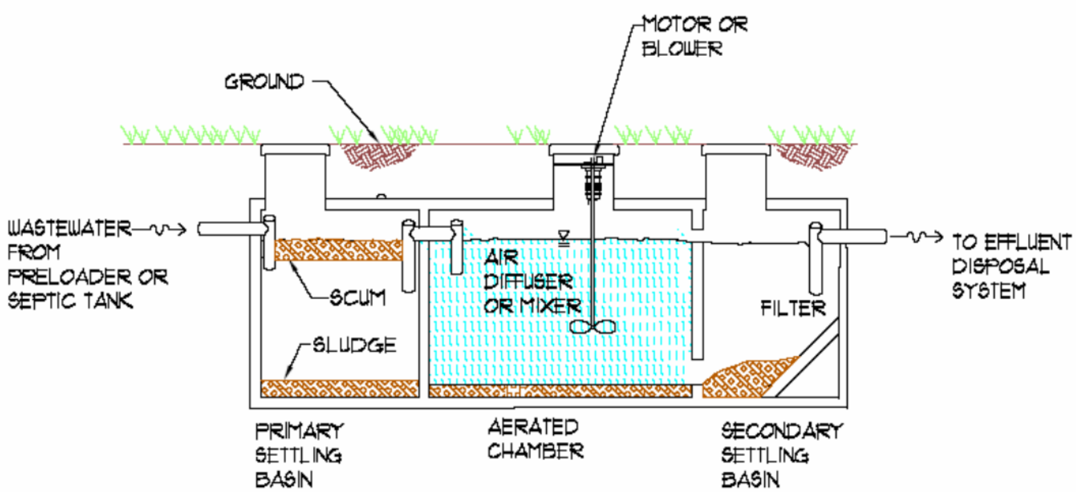

Figure AP2-1 Schematic of Suspended-Growth Flow-Through ATU

Advantages

- This type of ATU can achieve effluent quantity of BOD concentrations of 5-25 mg/L and TSS concentrations of 5-25 mg/L. This is equivalent to the standard “secondary” treatment level specified in the Federal Clean Water Act for publically-owned wastewater treatment plants across the USA.
- Since the biological process takes place in a aerobic environment where free oxygen is available, complete nitrification of ammonia is able to occur in the ATU.

Limitations

- Consideration should be given to determine how best to use available grades to allow gravity flow from the preloader (if present) to the ATU to the disposal system.
- Power is required to operate the blowers, pumps, controls, and monitoring and alarm systems in the ATU.
- Denitrification does not occur due to absence of an anaerobic environment. Therefore, effluent quantities of nitrate-N range from 10 to 60 mg/L. Because this type of ATU

alone cannot remove nitrogen, the pairing with a denitrifying disposal method may be necessary.

- ATUs are sensitive to high and low temperatures, heavy loading of solids, toxic chemicals (including chemical cleansers), power failures, and large influent flow variability.

Trained professionals should inspect the system every four to six months, along with sludge/scum pumping, as needed.

3.1.2. Combined Attached and Suspended Growth ATU w/Nitrification

This setup allows microorganisms to form a slime layer on the surface of submerged or semi-submerged media (Figure AP2-2). Wastewater is treated as it passes over the media. The system is similar to the suspended-growth flow-through ATU, except that the aerated chamber contains submerged media.

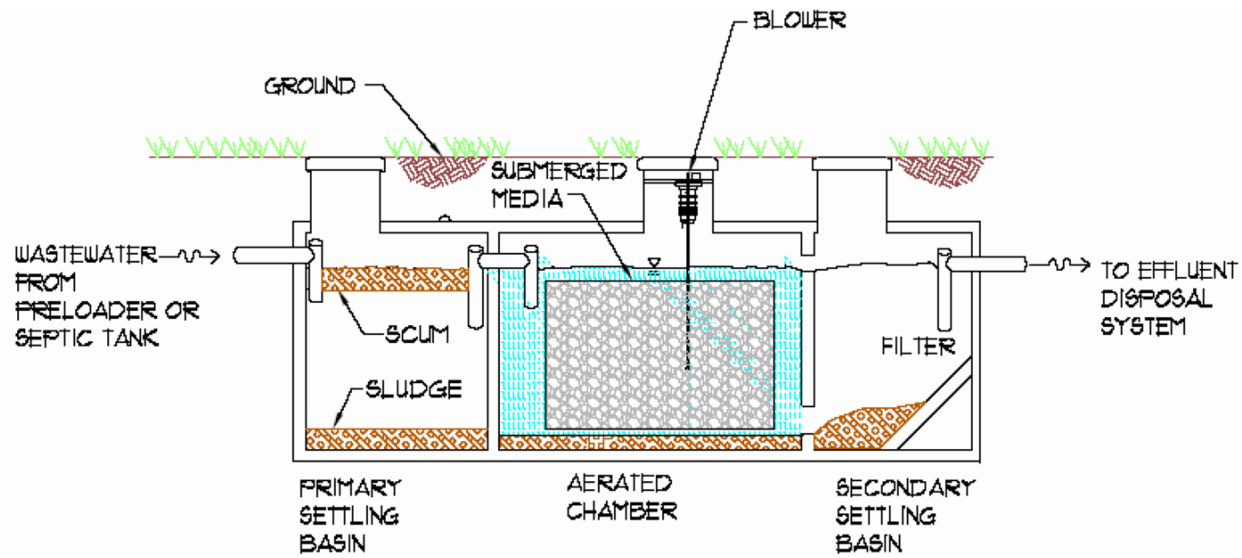

Figure AP2-2 Schematic of Combined Attached and Suspended Growth ATU

Advantages

- This type of ATU can achieve effluent quantity of BOD concentrations of 5-25 mg/L and TSS concentrations of 5-25 mg/L.
- Since the biological process takes place in a aerobic environment where free oxygen is available, complete nitrification of ammonia is able to occur in the ATU.

Limitations

- Consideration should be given to determine how best to use available grades to allow gravity flow from the preloader (if present) to the ATU to the disposal system.

- Power is needed to operate the blowers, controls, and monitoring and alarm systems in the ATU.
- Denitrification does not occur due to absence of an anaerobic environment. Therefore, effluent quantities of nitrate-N range from 10 to 60 mg/L. Because this type of ATU alone cannot remove nitrogen, the pairing with a denitrifying disposal method may be necessary.
- ATUs are sensitive to high and low temperatures, heavy loading of solids, toxic chemicals (including chemical cleansers), power failures, and large influent flow variability.

Trained professionals should inspect the system every four to six months, along with sludge/scum pumping, as needed.

3.2. Aerobic Treatment Unit-Nitrification/Denitrification

Some ATUs include both nitrification and denitrification capabilities. Flow-through varieties include a recirculation pump tp return nitrified water to the front of the system where it mixes with raw wastewater under anaerobic conditions and it is held to allow denitrification. Another tpe of system is the sequencing batch reactor (SBR) described below.

3.2.1. Sequencing Batch Reactor ATU w/Nitrification and Denitrification

In a SBR type ATU, all the aerobic, anaerobic, and clarifying processes occur within a single tank. The operating sequence includes at least the four following steps (Figure AP2-3), which can be cycled several times per day (e.g. one cycle every 4 hours):

1. Fill: tank is filled with raw wastewater to a predetermined volume.
2. Aeration: air is added for mixing and suspension of the microorganisms and the wastewater and for microbial oxidation of the waste including conversion of N into nitrate via nitrification;
3. Settle: aeration is turned off and the microorganisms/sludge settles to the tank bottom; concurrently, the contents become anaerobic which allows denitrification of the nitrate into nitrogen gas;
4. Decant: clarified portion is decanted as effluent. Cycle repeats.

These ATUs are designed to operate continuously using a control system of times, level sensors, and microprocessors.

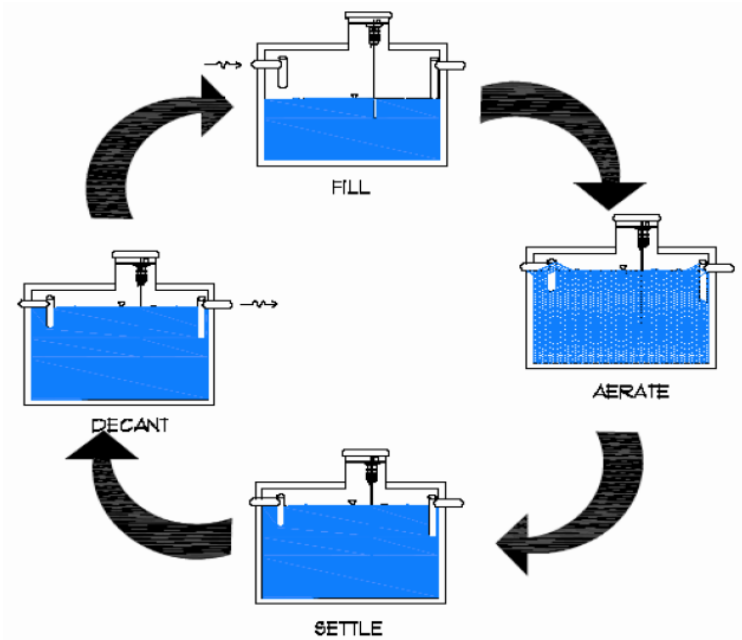

Figure AP2-3 Cycles of an SBR-type ATU

Advantages

- This type of ATU that can achieve effluent quantity of BOD concentrations of 5-25 mg/L and TSS concentrations of 5-25 mg/L.
- An SBR can provide both nitrification and denitrification through cycles of an aeration step and settling and decanting steps.
- Up to 50% of influent nitrogen can normally be removed (or possibly higher under ideal conditions).

Limitations

- Consideration should be given to determine how best to use available grades to allow gravity flow from the preloader (if present) to the ATU to the disposal system.
- Power is needed to operate the blowers, controls, and monitoring and alarm systems in the ATU.
- Accumulated sludge and scum must be removed on a regular basis to prevent carryover of these materials into the downstream disposal system.
- ATUs are sensitive to high and low temperatures, heavy loading of solids, toxic chemicals (including chemical cleansers), power failures, and large influent flow variability.

Trained professionals should inspect the system every four to six months, along with sludge/scum pumping, as needed.

3.3. Septic Tank

A septic tank serves as both a settling and skimming tank and partial anaerobic treatment. The baffles in the tank cause solids settle to the bottom and create a layer of sludge, while fats, oils, grease, and other floatables rise to the top and create a layer of scum (Figure AP2-4). Based on Hawaii's design requirements, a screen should also be installed on the effluent end to enhance solids removal and prevent clogging of the downstream disposal system. If high quality effluent is desired, a septic tank could be used to pretreat wastewater prior to a secondary treatment step, such as an ATU.

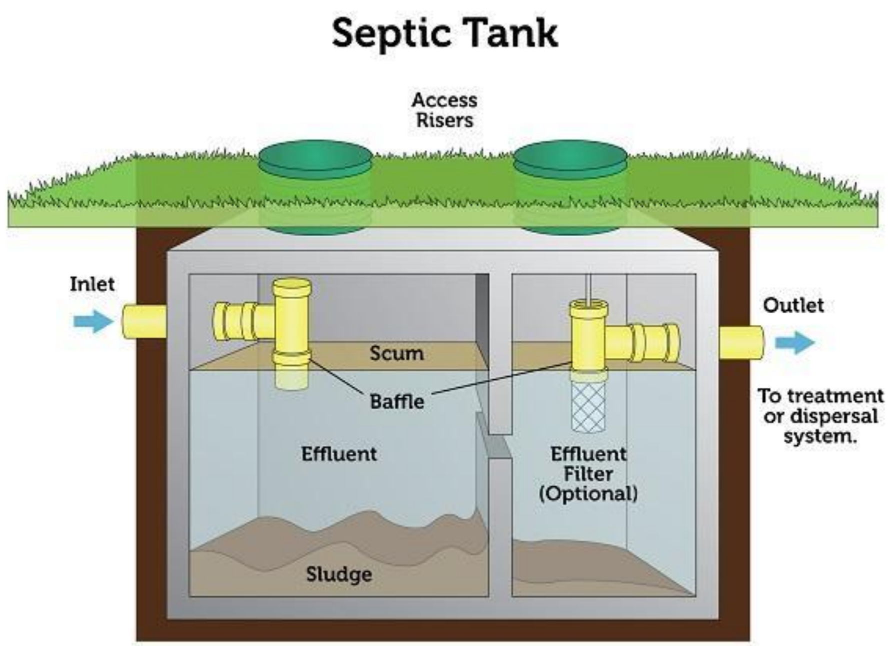

Figure AP2-4 Septic Tank with Two Chambers (United States Environmental Protection Agency, 2018)

Advantages

- Power is not required to operate a septic tank.

Limitations

- Accumulated sludge and scum must be removed on a regular basis to prevent carryover of these materials into downstream processes.

Maintenance costs are based on periodic pumping of solids and scum, as well as cleaning the effluent filter.

4. Wastewater Disposal Methods

The following describes various on-site wastewater disposal methods that have been reviewed for adaptability in Upcountry Maui. These systems are required to follow after the wastewater treatment step.

4.1. Absorption Systems

Absorption systems are designed to percolate liquids into the ground in consideration of the hydraulic permeability of the soil media. The percolation area is measured as the summation of the bottom area of all the trenches. These systems are generally shallow and are in the aerobic soil layer which provides oxidation of organic wastes and nitrification. The extent of such treatment is dependent upon the characteristics of the native soil, the loading rate, and other factors which can cause treatment to vary from 0% to as high as 90%. The absorption system also provides filtration of suspended solids and microorganisms.

4.1.1. Absorption Trenches and Gravel-less Systems

This disposal system is a subsurface wastewater infiltration system with trenches typically between 18 and 36 inches wide and 3 to 5 feet below grade (Figure AP2-5). Gravel-less trenches use materials such as plastic dome-shaped segmented chambers as substitutes for the traditional method of gravel bedding. This modification retains structural stability and hydraulic flow, while reducing the costs for gravel fill.

As wastewater percolates out of the trench, oxygen transfer from the air can maintain aerobic conditions in the trench.

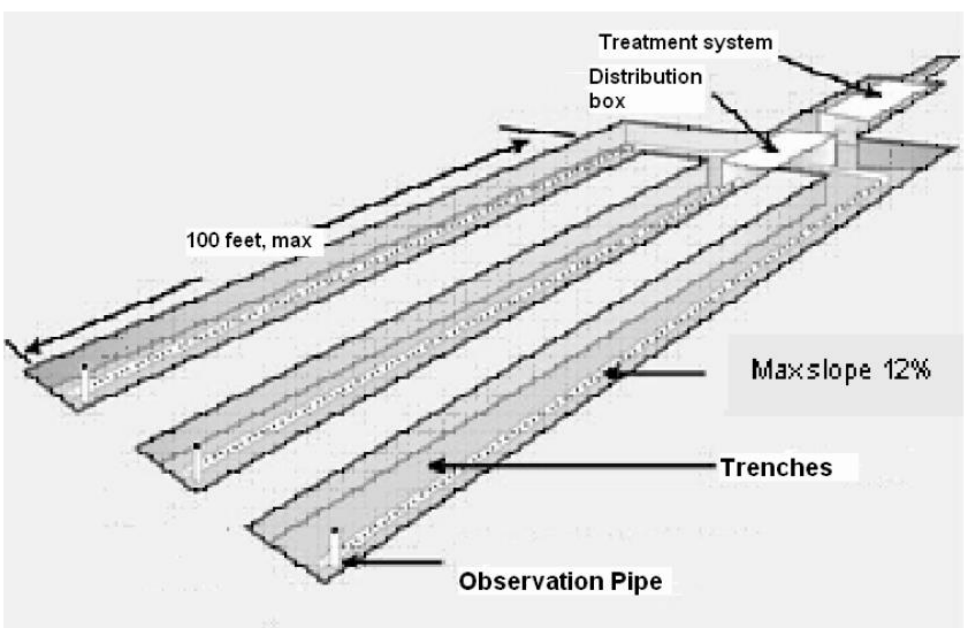

Figure AP2-5 Trench Disposal System

Advantages

- When used downstream of a septic tank, absorption trenches can achieve levels of less than 30 mg/L of BOD, 30 mg/L of TSS, and 13 CFU/100 mL of fecal coliform.
- When deployed downstream of an ATU, absorption trenches can achieve levels of 4 mg/L of BOD, 1 mg/L of TSS, and 13 CFU/100 mL of fecal coliform.
- No power is required and maintenance is generally not possible.

Limitations

- Trenches should not be used in terrain where the natural slope is too steep (>12% in HI).
- These systems cannot be used if groundwater is too close to the surface (minimum vertical separation of three feet is desirable)
- Large amounts of land may be needed, since the effective absorption area is at the bottom of each trench.
- Root intrusion can adversely impact trench performance.
- Overloading, rainfall, or unsuitable soils may cause contaminants to spill out into the surrounding soil, or surface water.

Periodic inspection of observation ports (if provided) can be used to determine whether water is accumulating in the trenches instead of percolating out. Upstream processes must be properly maintained to prevent excessive solids coming in and causing clogging of the voids in soil and adversely impacting the functionality of the absorption trench.

4.1.2. Absorption Beds

These are subsurface wastewater infiltration systems with beds at least three feet wide. They are similar to absorption trenches, but the area for disposal is excavated and a layer of gravel is installed with the distribution pipe on top (Figure AP2-6). An absorption trench system has a distinct section of undisturbed soil between the absorption trenches whereas the bed-type system is continuous. The percolation area is the area of the bottom of the absorption bed.

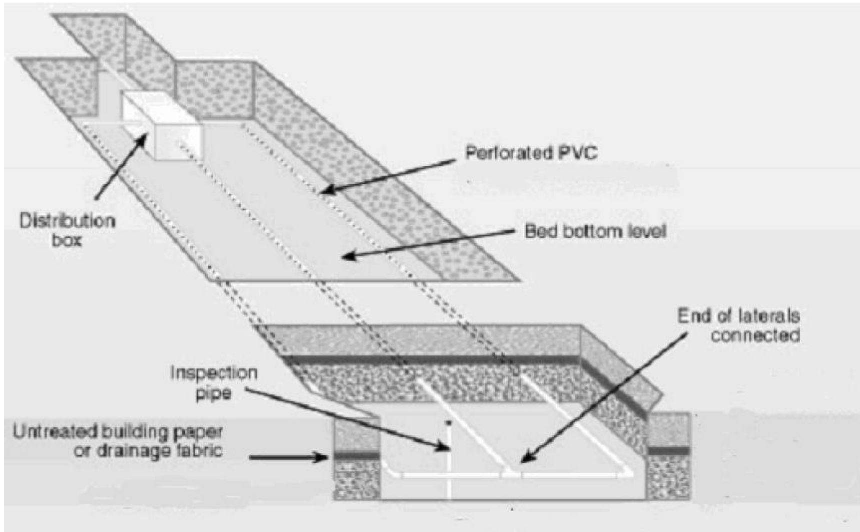

Figure AP2-6 Absorption Bed Disposal System

Advantages

- Same as absorption trenches.

Limitations

- Same as absorption trenches.

4.2. Seepage Pit

A seepage pit is similarly constructed to a cesspool, but it receives treated wastewater, whereas a cesspool receives untreated wastewater. These systems are generally constructed from reinforced concrete rings, with a diameter of 8 or 10 feet and a height of 2 feet, that are stacked in order to achieve the depth required (usually 15-30 ft). Each ring has large openings in the sides and looks like Swiss cheese. A concrete lid with a 4-inch inspection port is placed on top. Water percolates out from the sides and the bottom of the unit into the surrounding soil. The effective percolation area is measured as the pit sidewall area.

Advantages

- Seepage pits are the simplest and most compact method to percolate water into the ground.
- They are viable options when the available land area is insufficient for absorption beds or trenches, the terrain is steep, or when an impermeable layer overlies more suitable soil.
- These units can be maintained (accumulated solids from poorly-functioning upstream treatment units can be accessed and pumped out) unlike absorption trenches/beds.

Limitations

- Seepage pits generally cannot provide the same level of treatment as absorption bed and trench systems, but there have been few studies.

Proper functioning of a seepage pit relies heavily on maintenance of the upstream treatment process. This prevents clogging of the seepage pit. Otherwise, periodic pumping of any accumulated sludge will be required.

4.3. Disinfection

Disinfection is the killing of pathogens in wastewater. It is a form of additional treatment that is not often incorporated into OSDS systems and is placed here with disposal systems even though it is not a form of disposal. Most ATUs have the option of adding disinfection if desired by the owner or required due to proximity of the system to either groundwater or surface water. There are two main methods of disinfection: chlorination and ultraviolet (UV) light disinfection.

4.3.1. Chlorination

Chlorine is a powerful oxidizing chemical frequently used for disinfection of water or wastewater. Its common forms include chlorine gas, solid or liquid chlorine (calcium hypochlorite and sodium hypochlorite), and chlorine dioxide. Powder or tablets of solid hypochlorite are the form that can be used in onsite treatment systems. All forms of chlorine are toxic and corrosive, and require careful handling and storage.

Advantages

- The main advantages of chlorine are ready availability, low cost, and effectiveness against a wide range or pathogenic organisms. Chlorine can reduce fecal coliforms by 99 to 99.99% and can continue to exist as a residual in wastewater effluent.

Limitations

- Chlorine chemicals need to be stored and handled carefully.

A tablet system will require tablet storage and replenishments, inspection, and repair of system components as needed.

4.3.2. UV Disinfection

UV disinfection employs mercury-type lamps separated from the water by a quartz sleeve contained in a flow through stainless-steel reaction vessel (pipe). UV light acts as a physical disinfection agent due to the germicidal properties of UV in the range of 240 to 270 nanometers. The radiation penetrates the cell wall of microorganisms and causes cellular mutations that prevent reproduction. Effectiveness of UV disinfection depends on the clarity of the treated wastewater, UV intensity, time of exposure, and reactor configuration.

Advantages

- UV successfully inactivates most bacteria, viruses, spores, and cysts.
- In contrast to chlorine chemicals, this method does not involve handling or storing of hazardous or toxic chemicals.

Limitations

- A continuous power supply is required to operate the UV bulbs.
- Periodic cleaning of the quartz sleeves is required to ensure transmission of the UV radiation into the wastewater (monthly minimally).
- Bulbs must be replaced (typically annually)
- UV treatment is rendered ineffective in wastewater with low clarity due to bacteria being shielded by high turbidity and total suspended solids.

4.4. Presby Advanced Enviro-Septic and De-Nyte System

The Advanced Enviro-Septic® Treatment System is a network of 10-foot long pipes for further treating and percolating septic tank effluent. It consists of special pipes embedded in a specific type of System Sand. The pipes contain ridges, perforations with skimmers, geotextile fabric, green plastic fiber mat, and Bio-Accelerator® fabric. These work together to treat wastewater as depicted in Figure AP2-7 (Presby Environmental, 2018). Without using any electricity or replacement media, the Advanced Enviro-Septic® system can remove BOD, TSS, and provide full ntrification. Coupled with the add-on De-Nyte® unit, conversion of nitrate to nitrogen gas is possible (Figures AP2-8 and AP2-9) (Presby Environmental, 2018). Interconnected De-Nyte® cells can be placed 6 to 12 inches below the Advanced Enviro-Septic® system. These cells capture and treat nitrified wastewater using patented denitrification products (Presby Environmental, 2018).

Figure AP2-7 Presby Advanced Enviro-Septic® Treatment System (Presby Environmental, 2018)

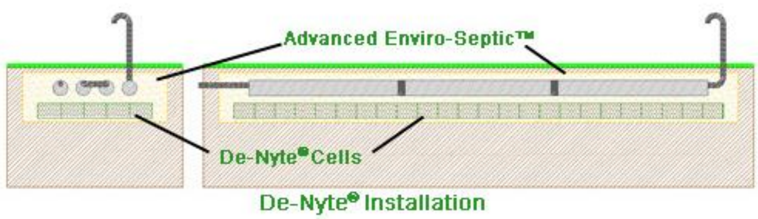

Figure AP2-8 Presby Advanced Enviro-Septic® Treatment System and De-Nyte® for Nitrogen Removal (Presby Environmental, 2018)

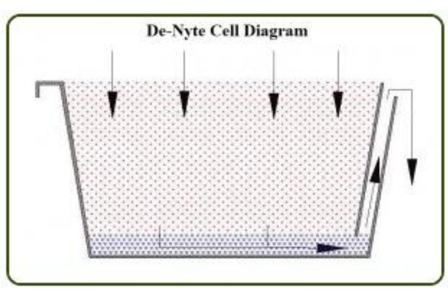

Figure AP2-9 Presby De-Nyte® Cell (Presby Environmental, 2018)

Advantages

- With De-Nyte®, total nitrogen removal is expected to be up to 75%.
- Passive system that does not need electricity. There are no moveable parts and no replaceable media.
- Enhanced treatment and disposal of wastewater are combined in this system.

Limitations

- This technology is relatively new to Hawaii, so a robust inspection and sampling program would be necessary.

Virtually no maintenance of the system is needed, but routine inspections and pumping of the upstream septic tank will be necessary.

5. Approval Required under Hawaii Administrative Rules

5.1. Evapotranspiration

Evapotranspiration (ET) combines direct evaporation and plant transpiration for wastewater disposal. Pretreated effluent (usually an ATU) is conveyed to a porous bed containing water-tolerant plants (Figure AP2-10). Wicking, or capillary action, draws water to the surface, where it is either taken up by the plants and transpired, or evaporated from the surface. Effluent that is not transpired or evaporated will percolate from the bottom of the bed. This type of system is known as evapotranspiration-infiltration (ETI).

These systems can also be designed with an underlying impermeable liner for a “zero-discharge” system. In this case, disposal is strictly dependent on evaporation and plant transpiration. Additionally, the liner allows the system to be placed above an Underground Injection Control (UIC) line or where there is shallow groundwater or proximate surface water such as a stream, lake or the ocean.

Other components that are typically included are drip or distribution lines, flushing or filtering mechanism, controller to automate dosing cycles, distribution pump, and alternating ET beds.

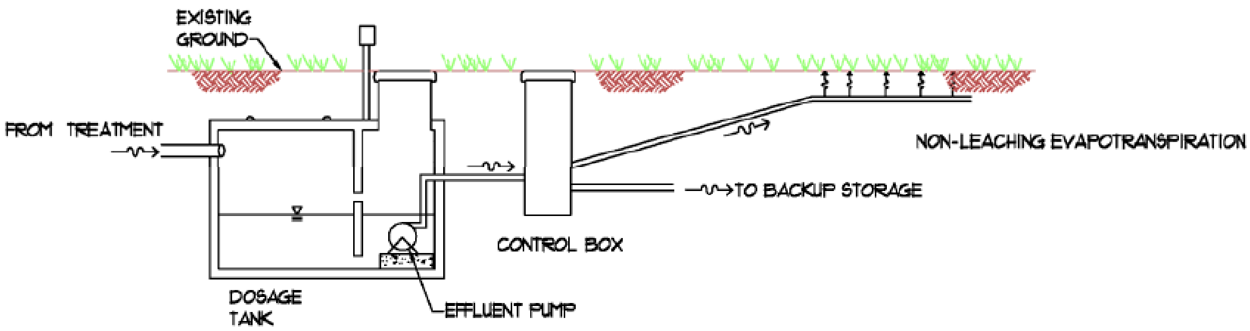

Figure AP2-10 Profile of Typical ET System

Advantages

- If an impermeable liner is included for a “zero-discharge” system, then 100% nitrogen removal is achieved.

Limitations

- Large surface areas are needed for year-round disposal. The size is controlled by a water balance based on rainfall and pan evaporation rates
- ET systems are more effective in arid climates where evaporation rates are much higher than precipitation rates.
- Recordkeeping of lysimeter (soil pore water sampler) data is required to ensure proper functioning.

O&M tasks will include simple inspection of observation wells, electrical costs for pumping, as needed, minor landscaping, and maintaining upstream processes to avoid overflow of solids into the ET bed.

5.2. Recirculating Sand Filter

Treated effluent is pressure distributed (such as by spray nozzles) to the top of a bed of sand, which is biologically treated as it percolates through (Figures AP2-11 and AP2-12). Carbon oxidation nitrification and denitrification can all occur. A portion of the water is pumped back to the pump chamber or the treatment process, and another portion passes on to a dispersal system such as drip irrigation or a seepage pit. The nitrate in the recirculated water undergoes denitrification under anaerobic conditions (Barnstable County Department of Health and Environment, 2018).

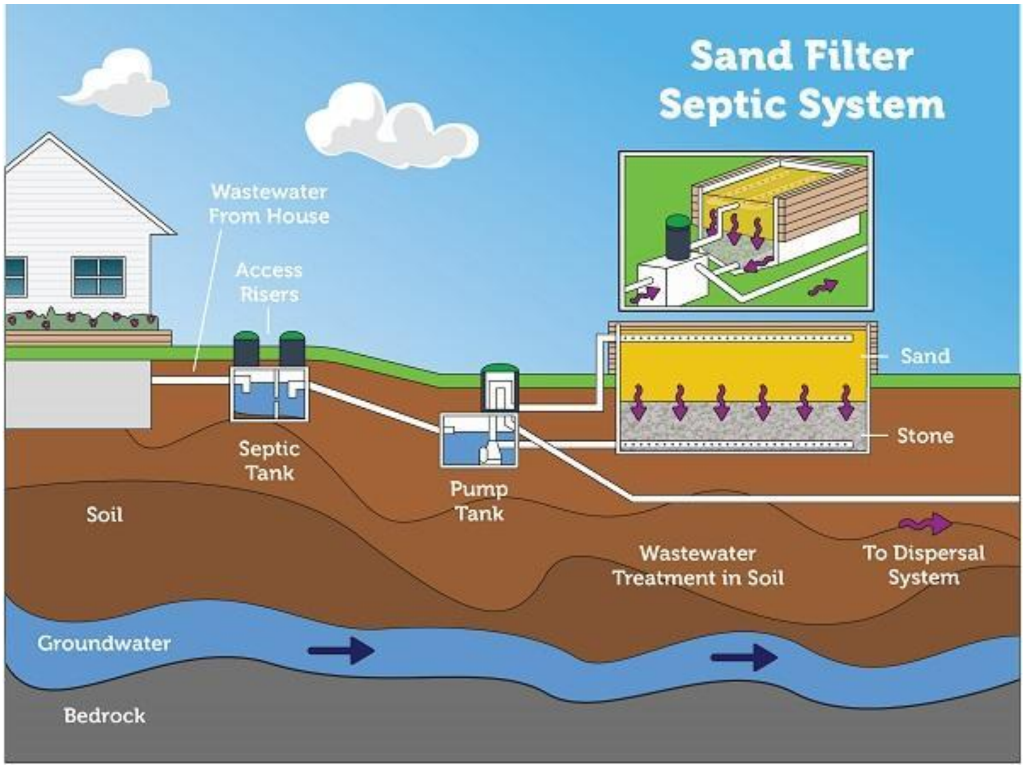

Figure AP2-11 RSF with Primary Treatment by Septic Tank (United States Environmental Protection Agency, 2018)

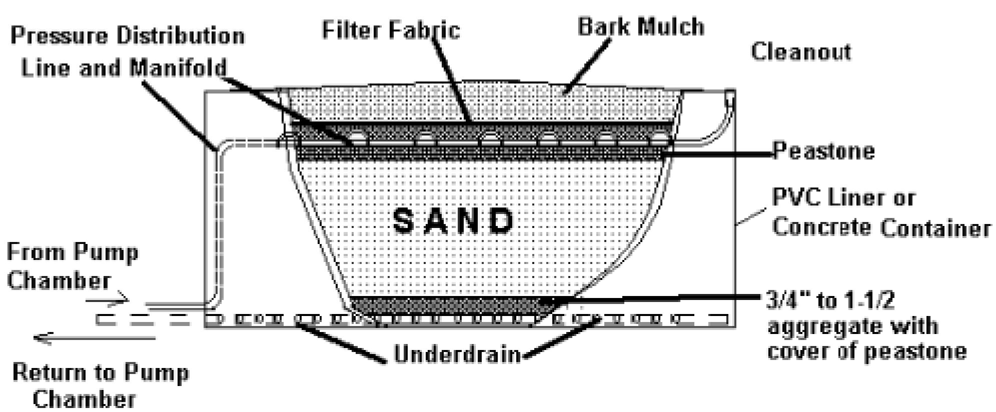

Figure AP2-12 Profile of RSF

Advantages

- RSFs can remove up to 50% total nitrogen.

Limitations

- Large land area may be required.
- Filters need to be covered to protect against odor, debris, algae fouling, and precipitation.
- A pump is needed for recirculating the wastewater.

Operational costs include electricity and labor. The filter should be inspected every 3 to 4 months, and the top layer of the filter media should be removed and replaced periodically.

6. Innovative Technologies

6.1. Constructed Wetland

A constructed wetland recreates the processes that occur in their natural environment. They may have visible water pools, however, those used as OSDSs typically keep wastewater flow beneath the media surface. This limits potential contact with wastewater and associated public health concerns. In general, the constructed wetland is an earthen basin or cell containing microorganisms, porous media, and plants (Figure AP2-13). The influent may be gravity-fed or pressure-dosed. The wastewater flows through the wetland and undergoes filtration, nitrification, denitrification, and adsorption. Longer detention times help to improve quality of the leaving effluent (Texas A&M AgriLife Extention Service).

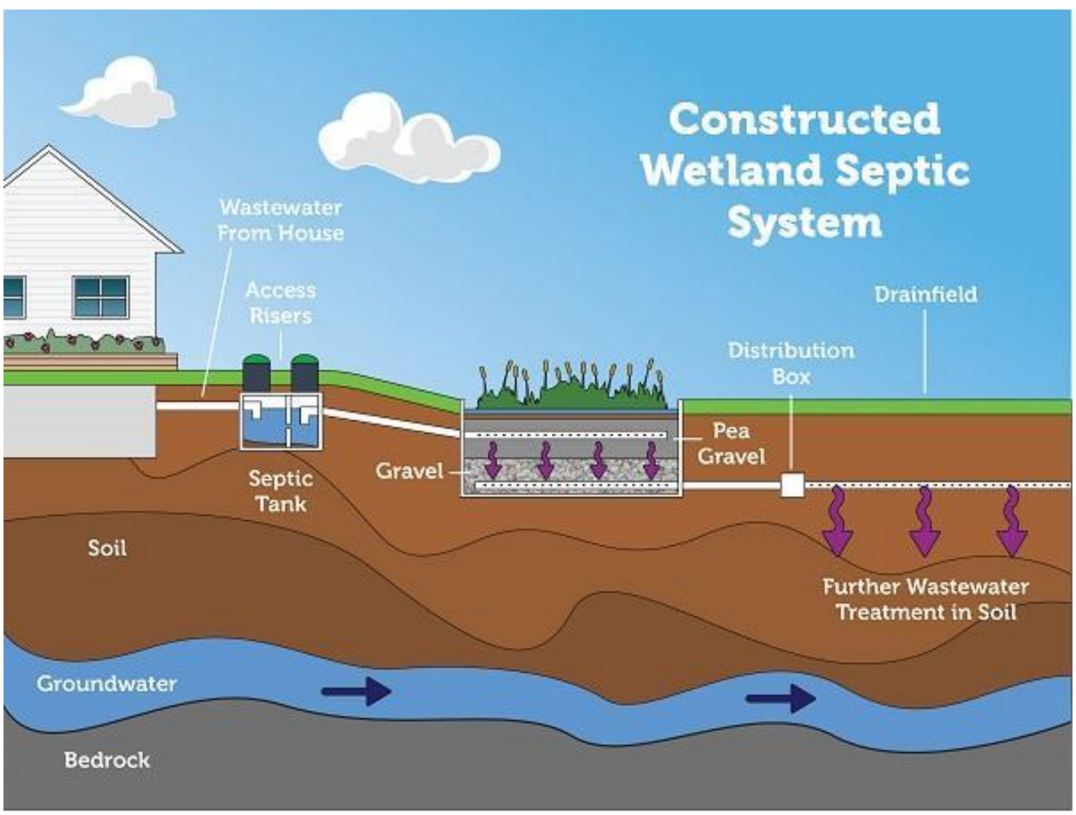

Figure AP2-13 Constructed Wetland with Primary Treatment by Septic Tank (United States Environmental Protection Agency, 2018)

Advantages

- A constructed wetland provides suitable conditions for denitrification to occur.
- Power is not required to operate a wetland.

Limitations

- Large land area may be required.
- It is important to maintain an even cross-sectional flow throughout the constructed wetland.
- The water level should be maintained in the cell during low- or no-flow periods so that the plants do not die.

The constructed wetland should be properly maintained to prevent surface ponding. Frequent inspection of the vegetation, inlet distributor, liner, berms or retaining walls, pumps, if present, and drainfield is required.

6.2. Drip Irrigation

This method of wastewater disposal uses a pump dosed system of pipes containing emitters (generally spaced every 12 inches) to deliver treated wastewater into the shallow root zone of the soil for dispersal (Figures AP2-14 and AP2-15). This allows for rates to be slow and controlled, as the dispersal system serves as both a slow rate biofilter and an ET system. The loading rate depends on soil characteristics, such as permeability, rainfall, evaporation, evapotranspiration rates, and level of nutrients (Sinclair, Rubin, & Otis, 1999).

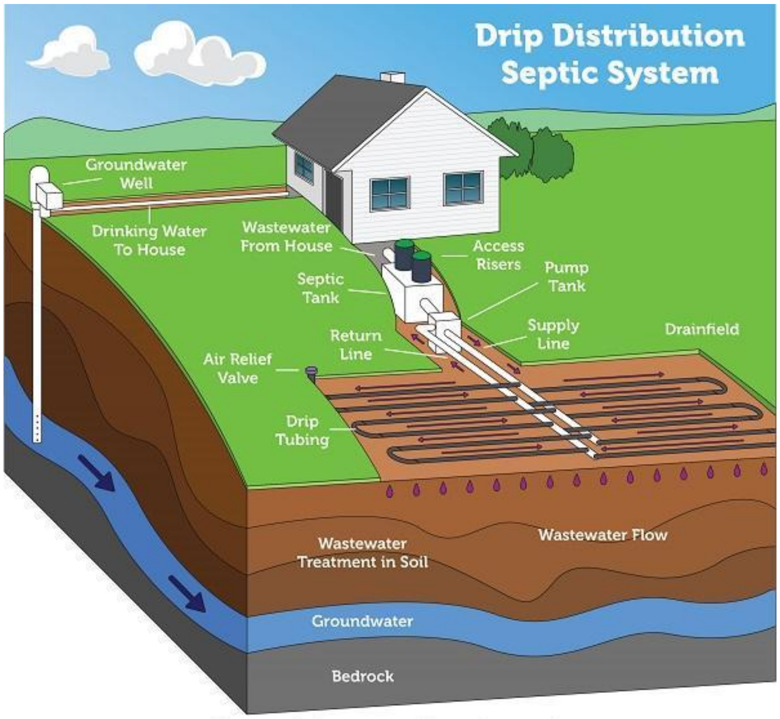

Figure AP2-14 Drip Irrigation System Shown with Septic Tank Treatment (United States Environmental Protection Agency, 2018)

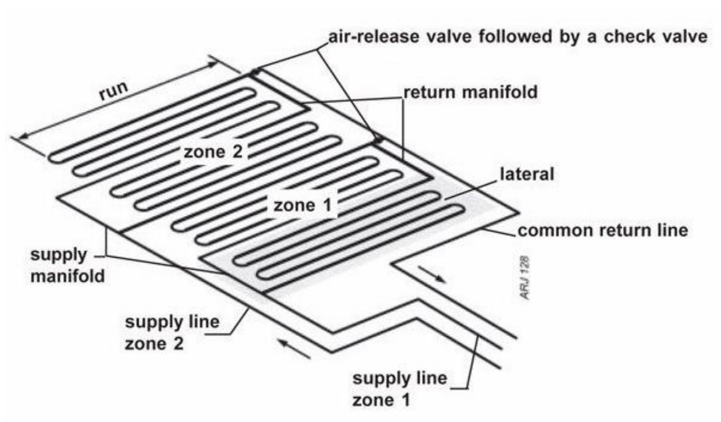

Figure AP2-15 Drip Irrigation Zones (Jarrett, 2008)

Advantages

- Reliable alternative for areas with low permeability, seasonal high water tables, or severe slopes.
- Ability to control dose/rest cycles allows for even spacing or dosing of effluent and facilitates wastewater infiltration by spreading it spatially and temporally.

Limitations

- In some cases, a large dose tank is needed to accommodate timed dose delivery to the drip absorption area.

6.3. Eliminite

This is a denitrifying septic system with two 1,500-gallon concrete tanks. As depicted in Figure AP2-16, the Eliminite system uses patented, proprietary treatment media called MetaRocks® to remove nitrogen. MetaRocks® provide a surface for nitrifying and denitrifying bacteria to thrive. The first 1,500-gallon tank is used as a septic tank, and the second tank has two chambers to house the MetaRocks® and provide BOD, TSS, and nitrogen removal. The Eliminite system is followed by a disposal system such as absorption or seepage pit. (Buzzards Bay Coalition, West Falmouth Village Association, Barnstable County Department of Health and the Environment, 2017) (Eliminite, Inc., 2018).

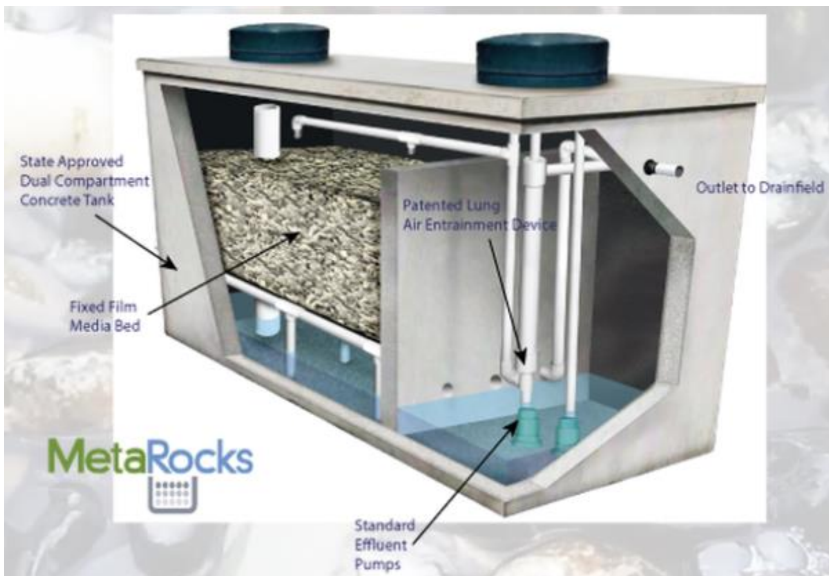

Figure AP2-16 Nitrogen Reduction by Eliminite's MetaRocks® (Eliminite, Inc., 2018)

Advantages

- Average total nitrogen removal is expected to be 62%.
- If a home already has a 1,500-gallon septic tank, then only one additional treatment tank is needed.

Limitations

- Pump operation and electrical power are needed.
- This technology is new to Hawaii, so a robust inspection and sampling program would be necessary.

6.4. NITREX

NITREX™ reactive media is contained in a tank that receives nitrified wastewater effluent. As depicted in Figure AP2-17, a typical setup includes wastewater sequentially passing through a septic tank, a nitrifying sand filter, the NITREX™ denitrifying filter tank, and then an absorption bed or trench for disposal. The NITREX™ media can also be placed in a lined excavation instead of a tank. The sand filter serves as a necessary nitrification step so that the NITREX™ can perform denitrification on nitrate-rich effluent (Lombardo Associates, Inc., 2018).

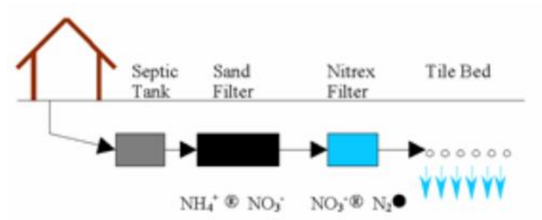

Figure AP2-17 Nitrogen Reduction by NITREX™ Filter (Lombardo Associates, Inc., 2018)

Advantages

- Average total nitrogen removal is expected to be up to 97%.
- There is no pumping or chemical addition requirement.
- The NITREX™ media has an expected performance period of 50 years.

Limitations

- This technology is new to Hawaii, so a robust inspection and sampling program would be necessary.

Virtually no maintenance of the system is needed, but routine inspections and pumping of the upstream septic tank will be necessary.

7. Emerging Technologies for Wastewater Treatment and Disposal

Various alternative methods have been investigated via extensive studies in other states. While these have been tested in limited setups and show potential in usability and effectiveness, their adaptability to Hawaii in general and Upcountry Maui conditions specifically, need to be assessed. Based on their promising results in preliminary studies, they are included as cesspool conversion options. Assumptions for site constraints and costing are based on the test study conditions and may vary significantly for Upcountry Maui.

7.1. Passive Nitrogen Reduction

The Washington State Department of Health and the University of Washington, Florida Department of Health, Barnstable County Department of Health, the New York State Center for

Clean Water Technology and Stony Brook University completed investigations of systems that operate relatively passively, with limited reliance on pumping, controls, and forced aeration (Hazen and Sawyer, 2014). Section 7.1.1 includes the technologies developed in Washington. The following Sections 7.1.2, 7.1.3, 7.1.4, and 7.1.5 describe methods based on full-scale prototype systems tested by the Florida Department of Health. Section 7.1.6 introduces another passive system designed by Barnstable County Department of Health. Sections 7.1.7 and 7.1.8 include setups by the New York State Center for Clean Water Technology and Stony Brook University that are currently being tested. Section 7.1.9 presents a selection of proprietary methods developed by onsite wastewater system manufacturers.

7.1.1. Recirculating Gravel Filter Systems

Each of these systems is based on a two-step process:

1) Under aerobic conditions, the effluent undergoes nitrification.
2) Under anaerobic conditions, denitrification occurs (Washington State Department of Health and University of Washington Civil and Environmental Engineering Department, 2012).

7.1.1.1. Recirculating Gravel Filter with Vegetated Woodchip Bed System

This system would be placed following a septic tank. Effluent could be transferred to an absorption bed or trench. There are three zones in this system, with effluent continually circulated through the first two zones. With each circulation cycle, a portion of the nitrified effluent is released to the third zone for denitrification. The different zones are denoted by numbers in circles in Figure AP2-18.

Zone 1: The septic tank effluent flows into the recirculating tank. As the effluent level rises in the tank, a float activates a timer to control a pump. The pump sends timed doses of effluent to the recirculating gravel filter in Zone 2.

Zone 2: The wastewater flows down through the gravel, and ammonia is converted to nitrate. The nitrified effluent exits through a slotted pipe at the bottom and about 80% flows back to the recirculating tank in Zone 1 with 20% flowing to Zone 3.

Zone 1 (repeated cycle): The nitrified effluent from Zone 2 mixes with additional septic tank effluent. Serving as a carbon source for bacteria, the septic tank effluent allows for some denitrification to occur here. The effluent is then pumped to Zone 2 to repeat the process.

Zone 3: This is a vegetated woodchip bed with constant submergence of the woodchips to create an anoxic zone. The bed can also be described as an anoxic subsurface constructed wetland. Denitrification occurs as the effluent flows horizontally through the bed. Plants such as cattails can also provide increased nitrate removal, as well as provide another carbon source. Finally, effluent from this zone would be transferred to a water level control basin and then a leach field (absorption bed or trench) (Washington State Department of Health and University of Washington Civil and Environmental Engineering Department, 2012).

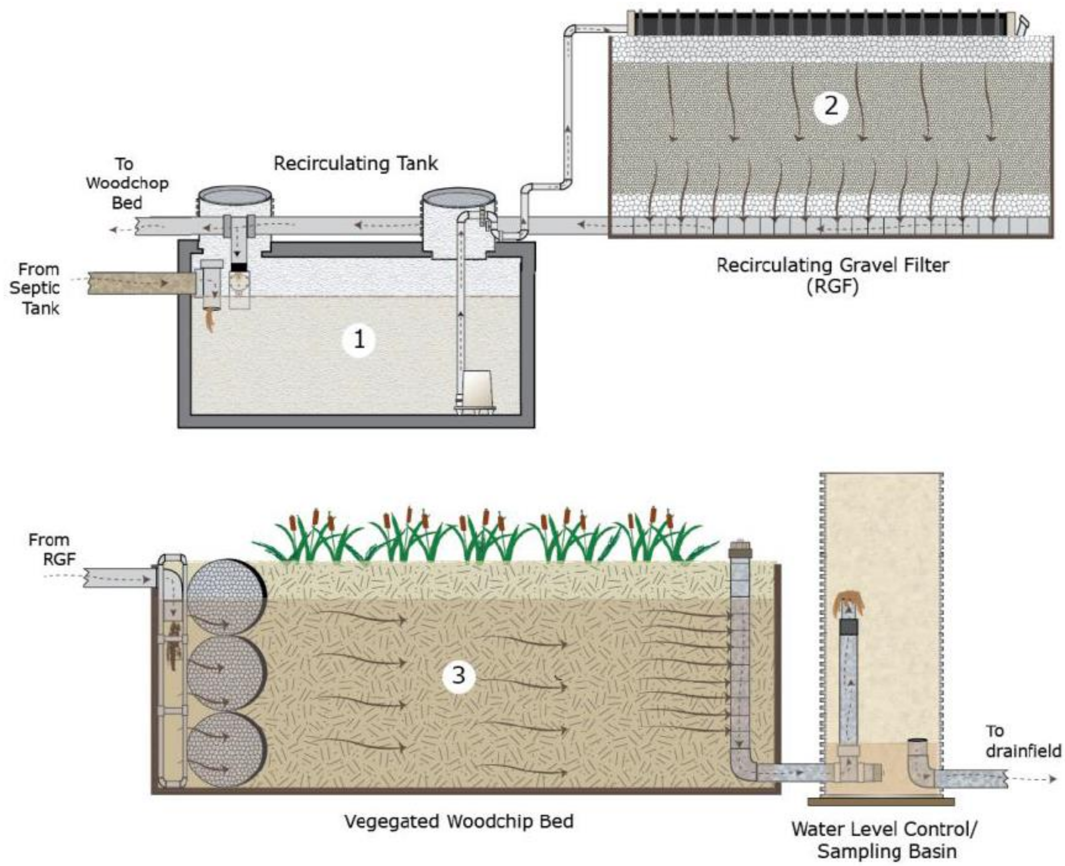

Figure AP2-18 Recirculating Gravel Filter with Vegetated Woodbed System (Washington State Department of Health and University of Washington Civil and Environmental Engineering Department, 2012)

Advantages

- Average total nitrogen removal was 92%.
- Local materials may be used for the woodbed media.

Limitations

- Pump operation and electricity are needed for the recirculation system.

Routine inspections should include the pump and control panel, adequacy of dosage frequency, and effluent filter on the septic tank outlet. The septic tank should also be maintained to ensure proper functioning of the subsequent treatment and disposal steps (Washington State Department of Health and University of Washington Civil and Environmental Engineering Department, 2013).

7.1.1.2. Enhanced Recirculating Gravel Filter System

This system is also designed to follow a septic tank and discharge to an absorption bed or trench. It can also be described of as a recirculating vertical-flow constructed wetland. As shown in Figure AP2-19, nitrification is to take place in the oxygen-rich top layer, and denitrification is to take place in the oxygen-free bottom layer. There are three zones, as shown by the numbers in circles in Figure AP2-19.

Zone 1 (beginning cycle): Septic tank effluent enters a mixing chamber at the bottom of the filter system. This chamber contains an anoxic gravel layer and organics in the wastewater are oxidized. The effluent continues to travel upwards through a slotted pipe, entering Zone 2.

Zone 2: This is a recirculating basin with a level-activated timer that controls a pump to send times doses to the filter bed in Zone 3.

Zone 3: In this oxygen-rich zone, wastewater is distributed into an oyster shell layer, which serves as a food source for Zone 3 bacteria. The wastewater continues to percolate down into a fine gravel layer, where nitrification occurs. The nitrified effluent then passes through a slotted pipe and is pumped back to the mixing chamber in Zone 1.

Zone 1 (repeated cycle): The mixing chamber now contains septic tank effluent and nitrified effluent. This mixture continues into the anoxic gravel layer in Zone 2 and denitrification occurs under these circumstances.

Zone 2 (repeated cycle): The process is repeated with doses sent to Zone 3, and as the recirculating tank fills to a certain level, the denitrified effluent is discharged to a leach field (absorption bed or trench) (Washington State Department of Health and University of Washington Civil and Environmental Engineering Department, 2012).

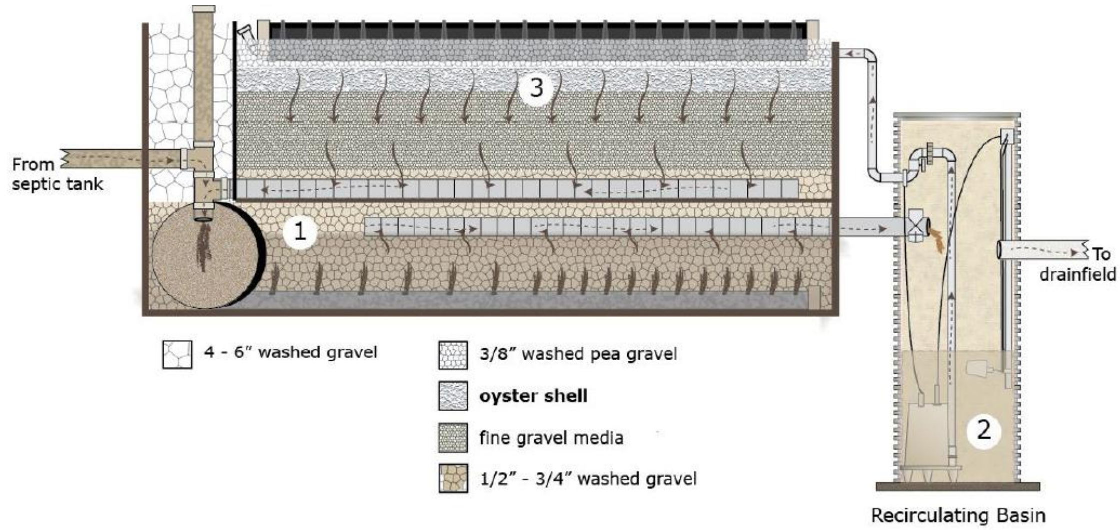

Figure AP2-19 Enhanced Recirculating Gravel Filter System (Washington State Department of Health and University of Washington Civil and Environmental Engineering Department, 2012)

Advantages

- Average total nitrogen removal was 82%.
- Local materials may be used for media.

Limitations

- Pump operation and electricity are needed for the recirculation system.
- Clogging occurred in the anoxic zone feed distribution piping. Further studies are needed for methods to prevent this.

Routine inspections should include the pump and control panel, adequacy of dosage frequency, and effluent filter on the septic tank outlet. The septic tank should also be maintained to ensure proper functioning of the subsequent treatment and disposal steps (Washington State Department of Health and University of Washington Civil and Environmental Engineering Department, 2013).

7.1.1.3. Vegetated Recirculating Gravel Filter System

This is similar to the enhanced recirculating gravel filter system, with nitrification occurring in the oxygen-rich top layer and denitrification occurring in the oxygen-free bottom layer. There are three zones, as shown in Figure AP2-20. Denitrification takes places after a complete cycle and effluent flows a second time through Zone 1.

Zone 1(beginning cycle): The system receives septic tank effluent. The effluent enters a gravelless chamber at the bottom of the filter system and then continues into the gravel layer of the anoxic Zone 1. Organics are oxidized, and wastewater travels horizontally across to an outlet pipe leading to Zone 2.

Zone 2: This is a recirculating basin with a level-activated time that controls a pump to send timed doses of effluent to the filter bed in Zone 3.

Zone 3: Wastewater is distributed into the oxygen-rich root zone of this vegetated bed. The effluent percolates down through a fine gravel layer, where nitrification occurs. The effluent then flows across a liner and down into an uncovered portion of the bottom gravel layer at the inlet end of the filter in Zone 1.

Zone 1 (repeated cycle): Here, the septic tank effluent and nitrified effluent from Zone 3 mix together and horizontally flow back through the anoxic gravel layer for denitrification to occur.

Zone 2 (repeated cycle): The process is repeated in the recirculating basin, and when it fills to a certain level, the denitrified effluent discharges to an absorption bed or trench (Washington State Department of Health and University of Washington Civil and Environmental Engineering Department, 2012).

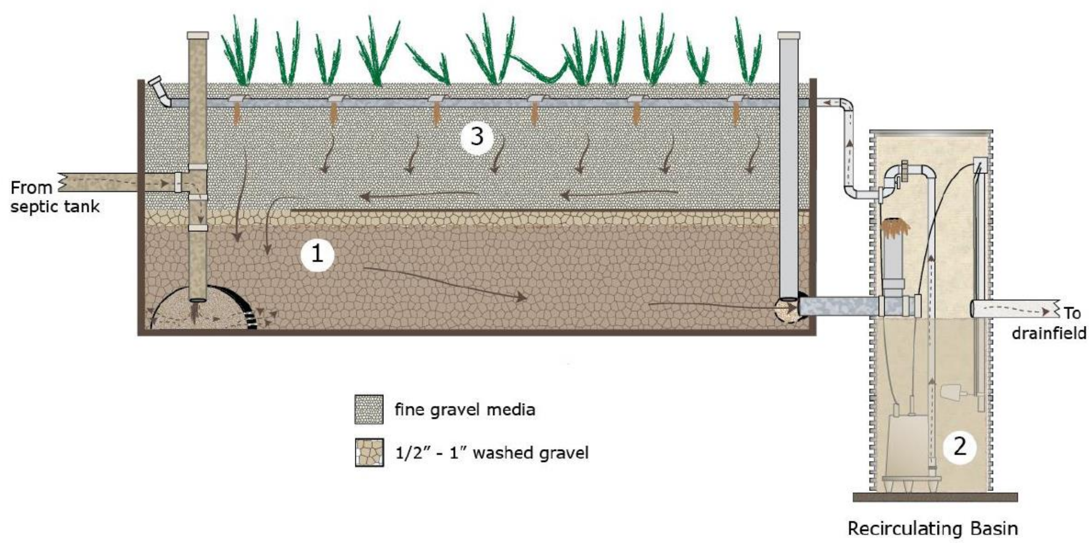

Figure AP2-20 Vegetated Recirculating Gravel Filter System (Washington State Department of Health and University of Washington Civil and Environmental Engineering Department, 2012)

Advantages

- Average total nitrogen removal was 69%.
- Local materials may be used for media.

Limitations

- Pump operation and electricity are needed for the recirculation system.
- Clogging due to plant root growth occurred in orifices of the aerobic bed distribution system. Therefore, plant selection is an important consideration.
- Clogging also occurred in the anoxic zone effluent line, but this was addressed using a filter.

Routine inspections should include the pump and control panel, adequacy of dosage frequency, and effluent filter on the septic tank outlet. The septic tank should also be maintained to ensure proper functioning of the subsequent treatment and disposal steps (Washington State Department of Health and University of Washington Civil and Environmental Engineering Department, 2013).

7.1.2. Treatment by In-Tank Unsaturated Biofilter with Recirculation and Disposal by Soil Treatment Unit

This method is an in-tank approach that treats septic tank effluent with a Stage 1 unsaturated biofilter with recirculation to a recirculation tank, and a soil treatment unit, such as an absorption trench or bed (Figure AP2-21). Stage 1 is a porous media biofilter that is unsaturated, allowing for nitrification to occur. Media that was used in the studies included expanded clay, sand, and oyster shells. Septic tank effluent is applied to the top of the media, resulting in a downward percolation of wastewater over and through the porous media biofilter bed. Due to nitrification, most of the wastewater nitrogen is converted to nitrate (Hazen and Sawyer, 2015).

With recirculation back to an anoxic holding tank, the nitrate-rich effluent is mixed with incoming wastewater. This provides favorable conditions for denitrification, prior to the disposal step (Hazen and Sawyer, 2015).

Advantages

- Total nitrogen removal is expected to be 50 to 70% prior to discharge to the disposal unit.
- Local materials may be used for biofilter media.

Limitations

- Pump operation and electricity are needed for the recirculation system.

Routine inspections (twice a year is required by Florida code) include pump operation and electrical connections, hydraulic inspection, flushing and cleaning of distribution lines, biofilter media life, and the recirculation system. The septic tank should also be maintained to ensure proper functioning of the subsequent treatment and disposal steps.

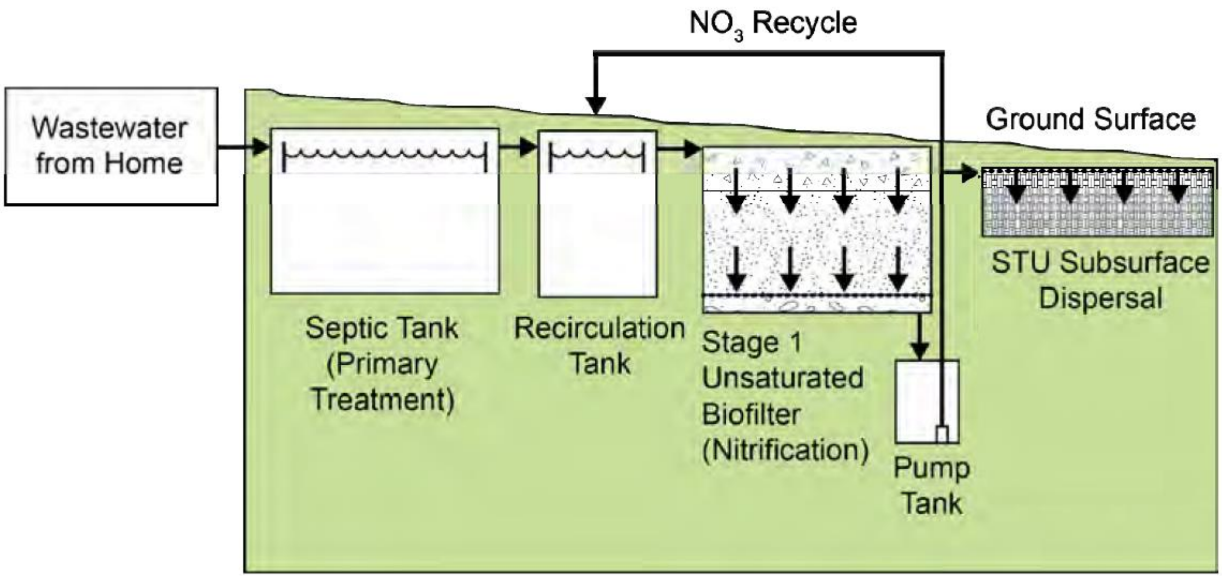

Figure AP2-21 Treatment by In-Tank Stage 1 Unsaturated Biofilter with Recirculation and Disposal by Soil Treatment Unit (Hazen and Sawyer, 2015)

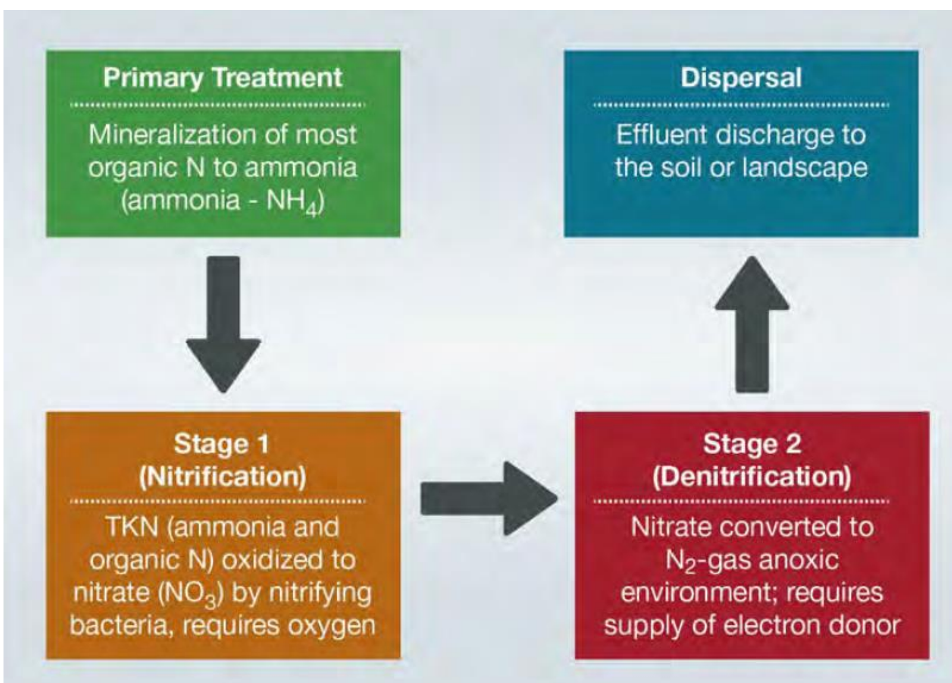

Figure AP2-22 Two-Stage Biofiltration Systems for Nitrogen Reduction (Hazen and Sawyer, 2015)

7.1.3. Treatment by In-Ground Unsaturated Biofilter in Native Soil Underlain by Saturated Biofilter in Liner and Disposal by Overflow into Surrounding Soil

Similar to the previously described system, this is an in-ground (non-tank confined) variation that treats septic tank effluent which is dosed at low pressure to an in-ground Stage 1 unsaturated biofilter in native soil. The Stage 1 biofilter is underlain by a Stage 2 lignocellulosic biofilter in a lined bed. The effluent is allowed to overflow the liner into surrounding soil. As shown in Figure AP2-23, nitrification occurs in Stage 1. Afterwards, the nitrate-rich water travels to the Stage 2 biofilter, which is saturated and therefore an anoxic environment suitable for denitrification. Studies have identified fine sand and lignocellulosic materials from woody plants as candidate media for Stage 2. Elemental sulfur was also tested as a media, although this type of media is more difficult to obtain and manage.

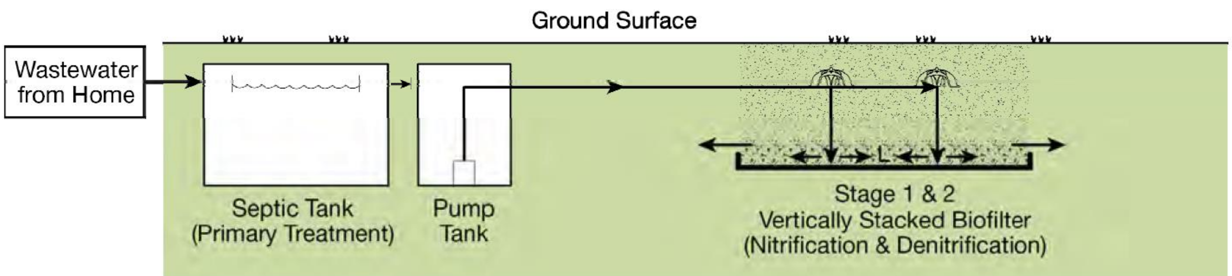

Figure AP2-23 Treatment by In-Ground Unsaturated Biofilter in Native Soil Underlain by Saturated Biofilter in Liner and Disposal by Overflow into Surrounding Soil (Hazen and Sawyer, 2015)

Advantages

- Total nitrogen removal is expected to be 50 to 70% prior to discharge from the system into the underlying soil for percolation disposal.
- Local materials may be used for biofilter media.

Limitations

- Pump operation and electricity are needed for the low pressure dosing system.

Routine inspections (twice a year is required by Florida code) include pump operation and electrical connections, hydraulic inspection, flushing and cleaning of distribution lines, biofilter media life, and the recirculation system. The septic tank should also be maintained to ensure proper functioning of the subsequent treatment and disposal steps.

7.1.4. Treatment by Single Pass or Recirculating Unsaturated Biofilter and Saturated Biofilter and Disposal by Soil Treatment Unit

This system also treats septic tank effluent via secondary treatment in a Stage 1 unsaturated biofilter and Stage 2 saturated biofilter. The denitrified effluent is then disposed of in an absorption bed or trench.

The Stage 1 biofilter hydraulics can be either single pass or recirculation (Figures AP2-23, AP2-24, and AP2-25). In Figure AP2-23, the pump tank can be run either with single pass or with a recycle stream for internal recirculation to spray nozzles located above the surface of the Stage 1 media. If topography allows for flow through the biofilters by gravity, then the system can be setup as in Figure AP2-24.

The Stage 2 biofilters can contain single or dual media, such as lignocellulosic/sand mixture and elemental sulfur.

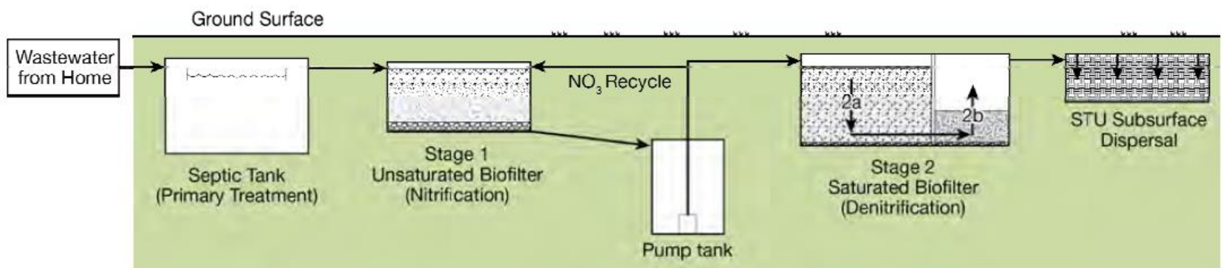

Figure AP2-23 Treatment by Recirculating Unsaturated Biofilter and Saturated Biofilter and Disposal by Soil Treatment Unit (Hazen and Sawyer, 2015)

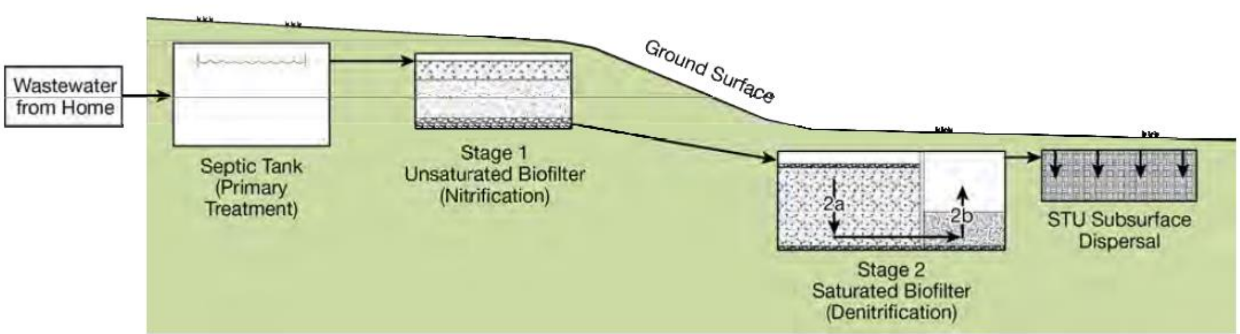

Figure AP2-24 Treatment by Gravity-Flow Single Pass Unsaturated Biofilter and Saturated Biofilter and Disposal by Soil Treatment Unit (Hazen and Sawyer, 2015)

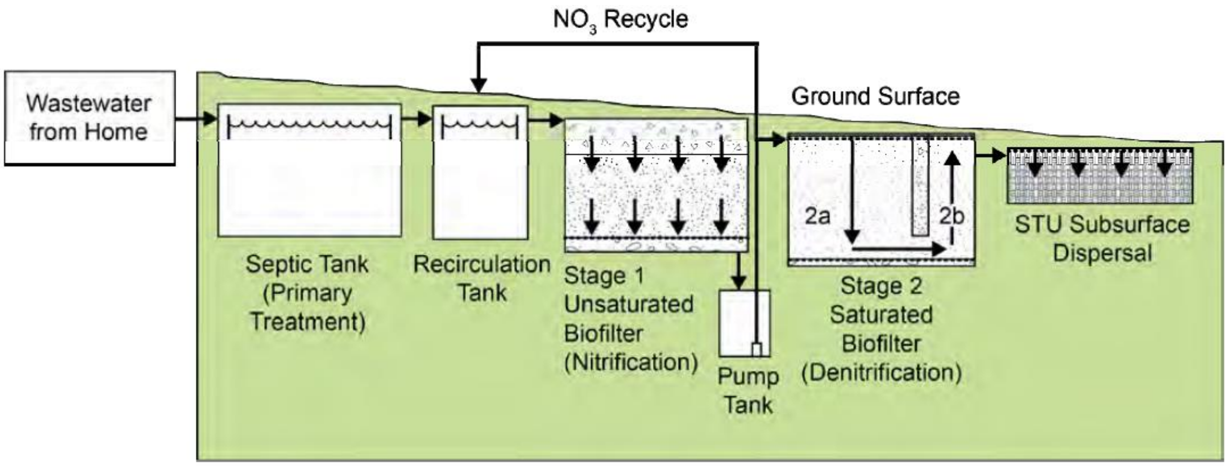

Figure AP2-25 Treatment by Recirculating Unsaturated Biofilter and Saturated Biofilter and Disposal by Soil Treatment Unit (Hazen and Sawyer, 2015)

Advantages

- Total nitrogen removal is expected to be 85 to 95% prior to discharge to the soil absorption system.
- Local materials may be used for biofilter media.

Limitations

- Pump operation and electricity will be needed if a recirculation system is included.

Routine inspections (twice a year is required by Florida code) include pump operation and electrical connections, hydraulic inspection, flushing and cleaning of distribution lines, biofilter media life, and the recirculation system. The septic tank should also be maintained to ensure proper functioning of the subsequent treatment and disposal steps.

7.1.5. Treatment by Unsaturated and Saturated Biofilter in Liner and Optional Second Saturated Biofilter and Disposal by Soil Treatment Unit

This is an in-ground variation of the previously described in-tank based system. Here, septic tank effluent is treated in a Stage 1 unsaturated biofilter stacked on a Stage 2 saturated biofilter. The effluent can continue to another Stage 2 saturated biofilter for further denitrification, or to a soil absorption system. Figure AP2-26 shows the additional Stage 2 filter and a drip irrigation soil treatment unit (Hazen and Sawyer, 2015).

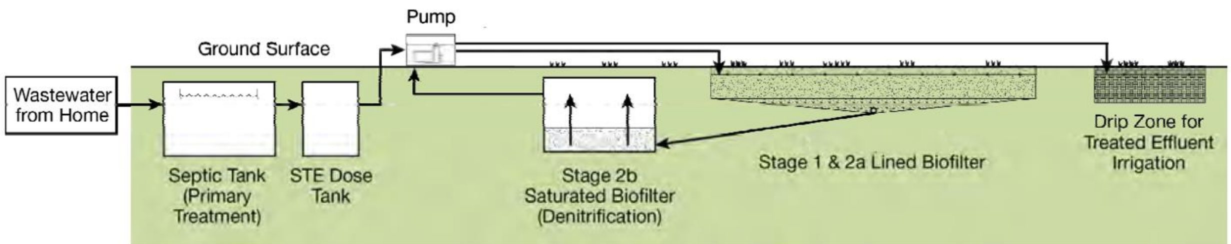

Figure AP2-26 Treatment by Unsaturated and Saturated Biofilter in Liner and Second Saturated Biofilter and Disposal by Drip Irrigation (Hazen and Sawyer, 2015)

Advantages

- Total nitrogen removal is expected to be 85 to 95% prior to discharge to the soil sbsorption system.
- Local materials may be used for biofilter media.

Limitations

- Pump operation and electricity will be needed if a recirculation system is included.

Routine inspections (twice a year is required by Florida code) include pump operation and electrical connections, hydraulic inspection, flushing and cleaning of distribution lines, biofilter media life, and the recirculation system. The septic tank should also be maintained to ensure proper functioning of the subsequent treatment and disposal steps.

7.1.6. Disposal by Layered Soil Treatment ("Layer Cake") Systems

The layer cake system treats septic tank effluent in a modified absorption bed or trench (Figure AP2-27). The modified leach field is a "layer cake" filtration system of 18 inches of sand and 18 inches of a sand and sawdust (or woodchips) mixture. The sand supplies oxygen for nitrification to occur, and the sand and sawdust mixture create an anaerobic environment for denitrification (Hilsman, 2016).

Figure AP2-27 Disposal by "Layer Cake" System (Buzzards Bay Coalition, West Falmouth Village Association, Barnstable County Department of Health and the Environment, 2017)

Advantages

- Total nitrogen removal is expected to be at least 50% and up to 90%.
- Local materials may be used for filter media.
- Low operating and maintenance requirements.

Limitations

- Pump operation and electricity may be required for conveying wastewater to the modified leach field if gravity cannot be utilized.
- The replacement interval of the sawdust/woodchips is unknown, but estimated at 50-70 years.

The septic tank and pump should be routinely inspected for proper functioning.

7.1.7. Disposal by Lined Nitrification/Denitrification Biofilter

Septic tank effluent is transferred through a low pressure distribution system comprised of a low energy pump and parallel, low pressure dosing pipes with drilled orifices (similar to an absorption bed). As the wastewater percolates down, it infiltrates the lined nitrification/ denitrification biofilter underlying the pipes. Nitrification and denitrification occur in the sand and sand/lignocellulose layers, respectively.

One configuration of the biofilter is a 6- to 8-inch soil cover, followed by a 12- to 18-inch nitrifying sand layer, and then a 12- to 18-inch sand and sawdust layer, as shown in Figure AP2-28. The system is lined to maintain saturation conditions and to allow effluent discharge to a dispersal system. An alternative configuration is presented in Figure AP2-29, where the denitrification step is designed in an upflow mode. This removes the need for an underdrain for effluent collection, and the effluent is simply discharge through overflow of the system (The New York State Center for Clean Water Technology, Stony Brook University, 2016).

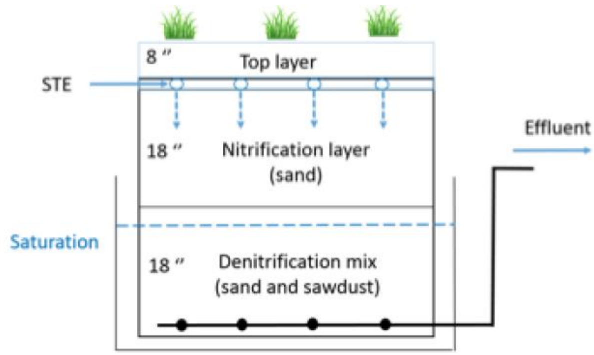

Figure AP2-28 Disposal by Lined Nitrification/Denitrification Biofilter (The New York State Center for Clean Water Technology, Stony Brook University, 2016)

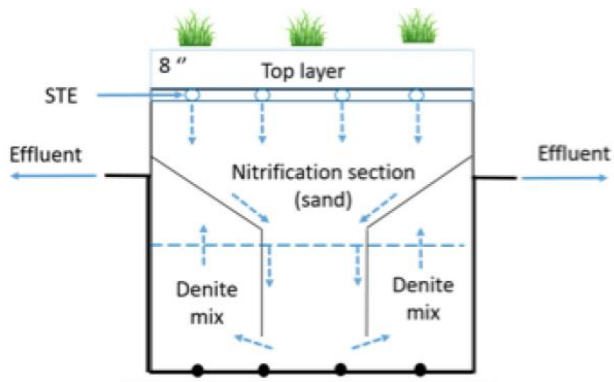

Figure AP2-29 Disposal by Lined Nitrification/Denitrification Biofilter with Denitrification Upflow Step (The New York State Center for Clean Water Technology, Stony Brook University, 2016)

Advantages

- Total nitrogen removal is expected to be up to 90%.
- Lined bottom provides more controllable system for sampling and monitoring.
- Processes are primarily driven by gravity and capillary forces.
- Saturated nature of sand and sawdust layer should minimize oxidation and degradation of the wood source over time.
- Local materials can be used for the biofilter media.

Limitations

- Pump operation and electricity needed for conveying septic tank effluent to the system.
- The replacement interval of the sawdust/woodchips is unknown, but estimated at 50-70 years.

The septic tank and pump should be routinely inspected for proper functioning.

7.1.8. Disposal by Sequence Nitrification/Denitrification Biofilter

This setup was designed to address the uncertainty of the wood material lifespan in biofilters. Literature reviews and calculations have indicated that the wood sources should persist for many decades; however, passive nitrogen reduction biofilters have not been in existence for more than a decade. Therefore, the lifespan of these wood sources remains an open question.

Septic tank effluent is transferred through a low pressure distribution system comprised of a low energy pump and parallel, low pressure dosing pipes with drilled orifices (similar to an absorption bed). As the wastewater percolates down, it infiltrates the sequence nitrification/ denitrification biofilter underlying the pipes. In this biofilter, the sand layer is coupled with an upflow woodchip biofilter in a tank that can be refilled as needed. As Figure AP2-30 shows, there is a 12- to 18-inch layer of nitrifying sand, which funnels the nitrified effluent into a collection pipe. Either by gravity or a low pressure pump, the effluent continues into the bottom of a tank filled with saturated woodchips. The effluent is allowed to flow up through the woodchip biofilter and then to a disposal system (such as absorption bed or seepage pit). The woodchip biofilter tank has a lid at the ground surface for easy accessibility to sample or replace woodchips (The New York State Center for Clean Water Technology, Stony Brook University, 2016).

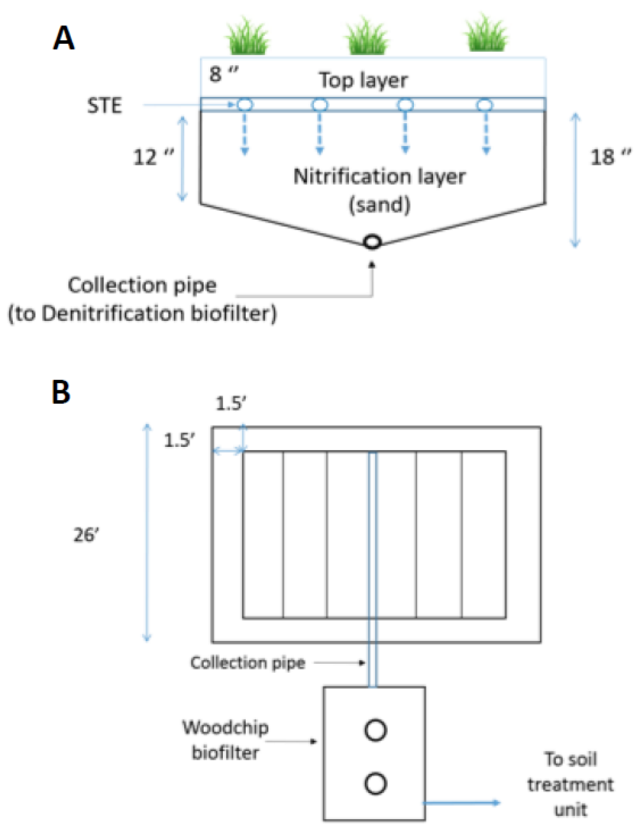

Figure AP2-30 Disposal by Sequence Nitrification/Denitrification Biofilter A) Front View of Nitrification Layer Configuration B) Plan View (The New York State Center for Clean Water Technology, Stony Brook University, 2016)

Advantages

- Total nitrogen removal is expected to be up to 90%.
- Processes are primarily driven by gravity and capillary forces.
- Saturated nature of sand and sawdust layer should minimize oxidation and degradation of the wood source over time.
- Local materials can be used for the biofilter media.
- Woodchip biofilter tank allows for convenient replacement of woodchips.

Limitations

- Pump operation and electricity needed for sending wastewater to the woodchip biofilter tank.

The septic tank and pump, if included, should be routinely inspected for proper functioning.

8. Alternative Toilets

Recently, alternative toilets with zero discharge of water have been developed for use in remote locations lacking water and/or electricity. It is important to note that in the State of Hawaii, household graywater (discharges that are *not* from toilets and kitchen sinks) systems are currently required to have an overflow pathway to a wastewater treatment and disposal system, as shown in Figure AP2-31 (Hawaii State Department of Health, 2009). Therefore, a household with an alternative toilet and a graywater reuse system for other sources of water must still have a wastewater treatment and disposal system.

Alternative toilet options include composting, incinerating, chemical, and oil flush toilets. The most commonly seen are compost toilets and incinerating toilets, which are discussed below. There has also been a recent exponential growth in alternative toilets research and a promising candidate is presented in this report.

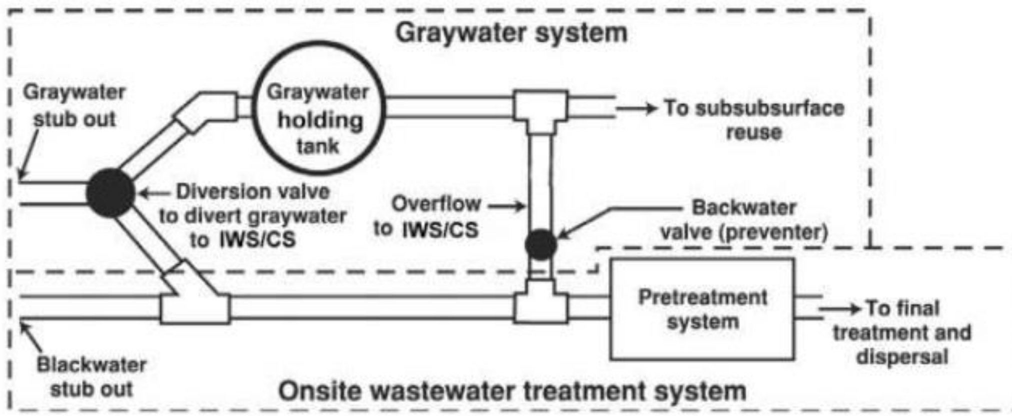

Figure AP2-31 Onsite Wastewater Treatment and Disposal Requirement for Graywater System (Hawaii State Department of Health, 2009)

8.1. Composting Toilet

A typical composting toilet (Figure AP2-32), is comprised of a composting reactor tank or bin connected to one or more waterless toilets in the house. For very small families, there are self-contained units with the compositing bin immediately under the toilet seat. Daily residential use may overload these smaller systems, so extra capacity may be necessary. Alternatively, a centralized tank reactor could be located in a basement or underground structure adjacent to the house. This may contain a rotating drum or could be built on a slope with fresh wastes at the top as the bottom of the pile ages. The reactor tank or bin contains and controls the decomposition of excrement, toilet paper, and carbon-based bulking agents such as wood chips, straw, hay, or grain hulls. Bulking agent materials break down quickly to prevent buildup of aerobic bacteria and fungi. Composting reactor tanks or bins may be single-chambered, continuous process, or multi-chamber batch units (National Small Flows Clearinghouse, 2000). The owner must remove and dispose of aged compost, turn the composting waste, and replenish bulking agents and odor control fluid (if desired)

No other liquid besides urine is present in the bin, allowing for aerobic decomposition of waste. Temperature should be properly maintained between 78 and 113° Fahrenheit for optimal decomposition rates. An exhaust system driven by a fan vents odors, carbon dioxide, and moisture from the reactor bin to the outdoors (the fan could be electricity-driven or a swamp cooler type). The decomposing material needs to be turned periodically to break up the mass and to keep the pile porous and aerated. The final material is about 10 to 30 percent of its original volume and must be properly disposed in accordance with health and environmental regulations (National Small Flows Clearinghouse, 2000).

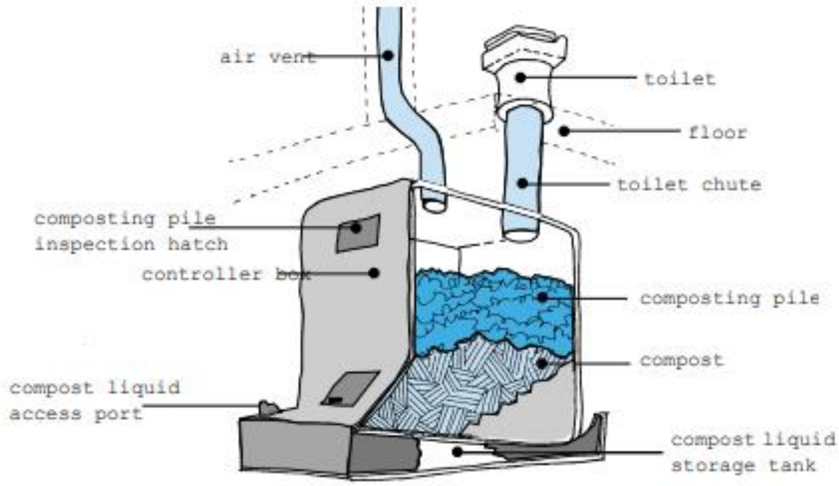

Figure AP2-32 Composting Toilet (National Small Flows Clearinghouse, 2000)

Advantages

- As a zero-discharge system, nitrogen will not be released into the groundwater.
- Since water is not needed for flushing, household water consumption is reduced.
- System consumes very little or no power.
- Residents may be able to install a reduced-size wastewater treatment and disposal system, minimizing costs and disruption to the landscape.

Limitations

- A high level of maintenance is required by the owner, such as periodic turning of the compost, daily addition of bulking agents, handling and disposal of compost, and preventing too much liquid in the composter.
- A power source is generally needed.
- Composting toilets must currently be used in conjunction with a graywater reuse system and wastewater treatment and disposal system in Hawaii.
- Composting excrement may be visible in some systems.
- There can b objectionable odors emitted from these systems.

Owners must be committed to properly maintaining the composting toilet system. Otherwise, removing the end-product and cleaning may be difficult and also cause health hazards and odor problems (National Small Flows Clearinghouse, 2000).

8.2. Incinerating Toilet

These types of toilets use electricity, oil, natural gas, or propane to burn waste to a sterile ash. A typical setup is depicted in Figure AP2-33. A paper-lined upper bowl holds newly deposited waste. The paper liner is replaced after each use. Flushing using a foot pedal causes an insulated chamber cover to lift and swing to the side while the bowl halves separate. The paper liner and its contents deposit into the incinerating chamber. When the foot pedal is released, the chamber cover reseals and the bowl halves close (National Small Flows Clearinghouse, 2000).

A "start" button on the toilet begins the burning process, which occurs after each individual deposit. An electric heating unit cycles on and off for about an hour while a blower motor draws air from the incinerating chamber over a heat-activated catalyst to remove odors. A fan then distributes the air through a vent pipe to the outdoors. The fan is also used to cool the incinerating unit. The entire cycle takes from about 1.5 to 1.75 hours per "flush" or use (National Small Flows Clearinghouse, 2000).

If the incinerating toilet runs on gas, then a toilet bowl is not present, and the waste drops directly into a holding chamber. Prior to the burning process, an anti-foam agent is added to reduce the risk of liquid wastes boiling over. The toilet seat is lifted, and a cover plug is inserted to act as a fire wall (National Small Flows Clearinghouse, 2000).

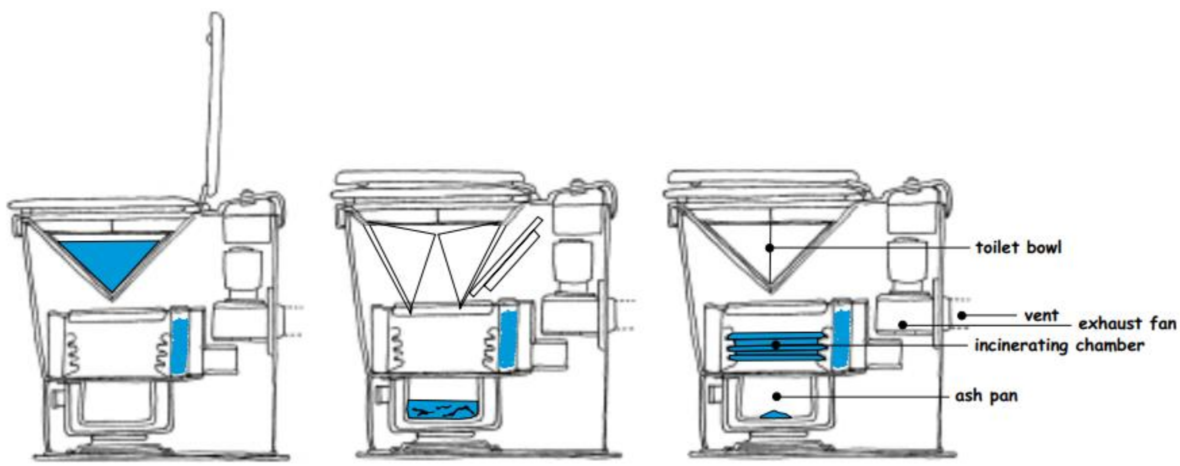

Figure AP2-33 Incinerating Toilet Shown with Seat Cover Up, Seat Cover Down and Incinerating Chamber Opened, and Seat Cover Down and Incinerating Chamber Closed (Left to Right) (National Small Flows Clearinghouse, 2000)

Advantages

- As a zero-discharge system, nitrogen will not be released into the groundwater.
- Since water is not needed for flushing, household water consumption is reduced.

- Residents may be able to install a reduced-size wastewater treatment and disposal system, minimizing costs and disruption to the landscape.

Limitations

- Care must be taken to minimize electrical hazards.
- A power source is needed.
- The toilet cannot be used during the incinerating cycle.
- Incinerating toilets must currently be used in conjunction with a graywater reuse system and wastewater treatment and disposal system in Hawaii.

Maintenance includes regular cleaning and monitoring of the blower, mechanical parts, ash collection pan, upper bowl, and odor-removing catalyst (National Small Flows Clearinghouse, 2000).

8.3. Nano Membrane Toilet

In 2011, the Gates Foundation launched the Reinvent the Toilet Challenge, where scientists, universities, and companies created new toilets that did not require a sewer system to treat human waste. The various inventions were presented at an exposition in November 2018, and one of the promising candidates is the Nano Membrane Toilet (Yu, 2018).

This toilet reportedly will operate without water or a power source. Although it is not clear how it will be self powered. When the toilet lid is closed, a rotating mechanism processes the deposited waste. A “nanostructure membrane” filters out pathogens from the liquid waste. The processed liquid can then be stored as reusable water in an underlying tank. It could be reused at the household level in washing or irrigation applications. Solids are allowed to separate through sedimentation and then burned via a combustor and converted into electricity. More specific steps are detailed in Figure AP2-34. The prototype is in progress and field testing will begin in 2019 (Yu, 2018) (Perry, 2018). If testing is successful, approval will need to be granted by the U.S. Environmental Protection Agency and HDOH prior to use in Maui residential homes.

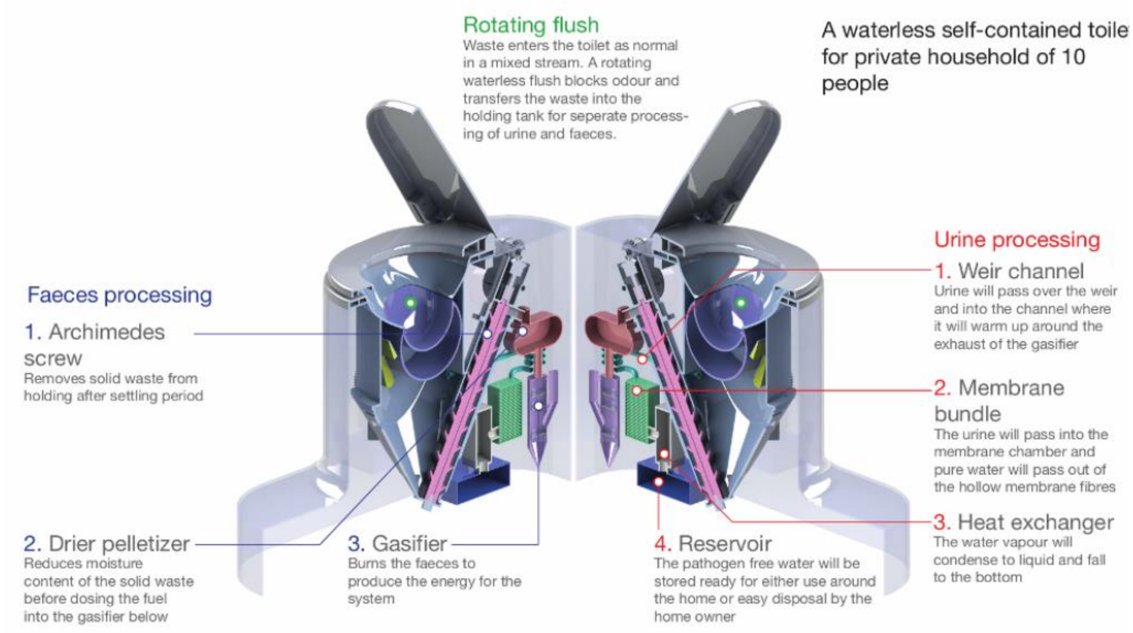

Figure AP2-34 Nano Membrane Toilet (Bill & Melinda Gates Foundation, Cranfield University, 2012)

Advantages

- As a zero-discharge system, nitrogen will not be released into the groundwater.
- Since water is not needed for flushing, household water consumption is reduced.
- Residents may be able to install a reduced-size wastewater treatment and disposal system, minimizing costs and disruption to the landscape.

Limitations

- The system is pending completion of a prototype, field testing, and federal and state approval.
- Composting toilets must still be used in conjunction with a graywater reuse system and wastewater treatment and disposal system.

9. Sewering

A sanitary sewer system connected to a wastewater treatment plant is an alternative to individual onsite wastewater treatment and disposal systems. Sanitary sewer systems are broadly categorized as decentralized or centralized, and these are described further below.

9.1. Decentralized Sewering

Groups of homes can be connected via a cluster system like the one in Figure AP2-35. A common area is designated as a satellite treatment facility or just a common disposal system. Typically, a cluster may have each residence on a septic tank, combine the effluent from those septic tanks in an equalization tank, and discharge to a common soil absorption system. Additional treatment may be included by a large, common aerobic treatment system or denitrification system. A cluster could also have a single, large septic tank to collect each household's wastewater (Water Resources Research Center and Engineering Solutions, Inc., 2008).

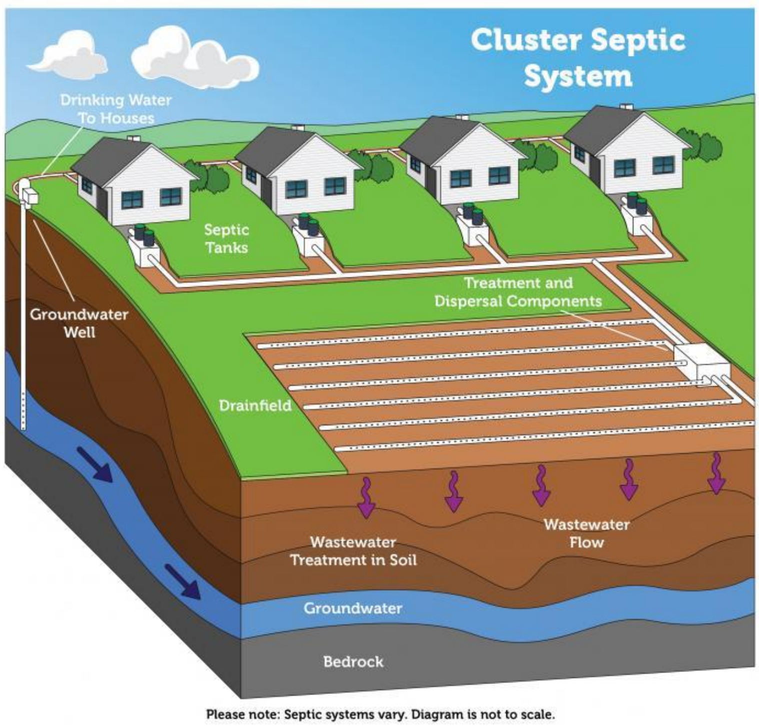

Figure AP2-35 Cluster System (United States Environmental Protection Agency, 2018)

Advantages

- Contaminants are transferred from each residence to a single treatment and disposal unit that can be more economical and better controlled and monitored.
- If the treatment and/or disposal components include denitrification, total nitrogen removal should be at least 50%.
- Literature review has indicated that for total flows between 5,000 and 15,000 gallons per day, cluster systems are more economical than individual onsite systems.

Limitations

- Contaminants are placed in a single confined space, rather than over a larger area that individual systems would use.
- Caution must be taken to prevent groundwater from ponding under the cluster system.
- Continuous monitoring must be performed using groundwater wells upstream and downstream from the final disposal site.
- Regulations also require alternating absorption beds and reserving land space for backup in case an absorption bed fails.
- Regulations would require employment of a state-licensed operator to monitor and maintain such systems.

9.2. Centralized Sewering

Decentralized sewering can be extended to centralized sewers. For this option, a larger number of homes are connected by a more extensive sanitary sewer network. The combined wastewater effluent is managed at a centralized wastewater treatment plant as depicted in Figure AP2-36.

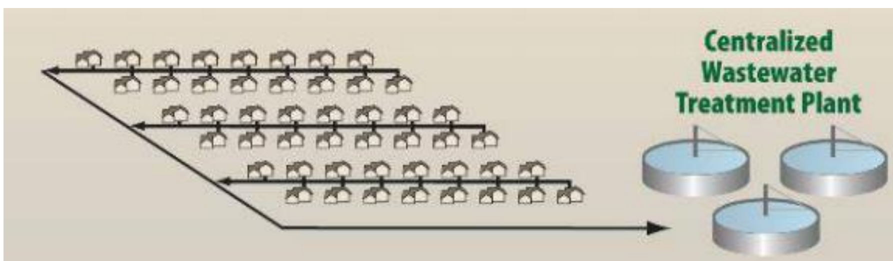

Figure AP2-36 Centralized System (D'Amato, 2016)

Advantages

- Contaminants are transferred from each residence to a single treatment and disposal unit that can be more economical and better controlled and monitored.
- Depending on the specific treatment components at the wastewater treatment plant, total nitrogen removal could reach 100%.

Limitations

- Large collection systems are expensive to construct and maintain and may also involve pump stations with associated power costs.
- Wastewater treatment plants require high levels of cost, power, labor, and management.

10. Point of Use Treatment

Instead of treating wastewater prior to dispersal into the ground, it is possible to continue the status quo and further contaminate the underlying ground water. If that groundwater is needed as a potable supply, point-of-use treatment can be implemented at the wellhead prior to distribution as drinking water. This treatment would have to satisfy HDOH's Safe Drinking Water Act to ensure quality drinking water. The specific treatment processes required would include at least a process to remove nitrate such as ion exchange, a process to remove trace organics such as activated carbon and a disinfection process such as chlorination. Regular sampling/analysis/reporting as well as obtaining renewable permits would be required. State-certified oparators wouldl be needed. The costs of treatment would include construction and operation and maintenance including chemicals, labor and electricity. This option would not meet Act 125, which requires all cesspools to be replaced.

Advantages

- Expense of upgrading cesspools is avoided.
- Drinking water quality remains protected.

Limitations

- Does not meet Act 125 regulation. Cesspools will still need to be replaced or upgraded.
- Does not prevent nitrate contamination in groundwater.

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Appendix III: Stakeholder Workshop Group Notes (transcribed and un-edited)

March 12, 2019

Upcountry Cesspool Stakeholder meeting WG

Look into factor of chlorination (chloramines?) leading to nitrates in groundwater

Phone group:

- Sina Pruder
- Sean O'Keefe
- Joanna Seto
- Lorrin Pang

Bookends

What is a good option for the cost alternative (lowest cost)

Stay away from the "someone else paying" scenarios for now

Sean: we don't have $ info

- The options document sent out was helpful to understand the different technologies available, but there was no cost info; they can't evaluate what would be the cheapest if they are lacking cost info
- Important information is lacking in order to be able to address the cost objective
- Cost estimates are challenging, from engineering standpoint, without details of each given case
- Range and average would be helpful; what's likely for Maui? Costs will be different from Oahu

Don't want to just buy the cheapest; could get a cheap tank, but cheap materials will fail, run risk of collapse with pumping

Septic and leach field might be the cheapest; the question is whether this is the solution?

- Great to keep in mind for future exercise on comparing across objectives

Is this fair? Pineapple pollution example. Pineapple fields have pesticides and chemicals in the soil that will last a very long time; not fair to future landowners, Nearby landowners, downhill landowners

- We talk about how upcountry drinking water is not from the aquifer; it comes from elsewhere (east Maui); 1 solution regarding fairness = bring in water for the downhill people. Bring in water for the people that have already-polluted water from the plantations.
- Fairness: polluting groundwater doesn't affect polluter, it affects people downhill.

Certainly, we don't want to add more N to the soil; that impacts future; takes 25 years to get to the aquifer.

- Want to protect; avoid expense, avoid further polluting

Source reduction options? Separating N in wastewater; source separation toilets; urine is where majority of the nitrogen in wastewater comes from.

- Where does it go?

Current Tax credit incentive has limitations:

- $10,000 max doesn't cover the full cost of a system
- Max # of available credits; statewide limit covers barely a fraction of cesspools in upcountry alone.
- Option that could make $ easier to bear: no / low interest loan programs
- How does cost compare to sewer fees? Over lifetime, Monthly cost could be similar to sewage fees; what would 20 years of sewage fees look like?

Clean Water Act loan programs; could be an underutilized source of financial assistance

Need a support system to implement upgrades

Composting toilets are cheaper; 10% cost of septic system

- Could be attractive to funders, who may be more inclined to subsidize cheaper options if they're just as efficient
- Issues to consider: graywater regulations, homeowner has to "get down and dirty with their waste"

Thinking outside the box – graywater N from soaps

- Soap regulations?
- Keeping your waste on your land, instead of it going elsewhere

  "At least your stuff is on your land"

Everybody wins

Presby system reduces N; meets NSF 40, maybe even 245? (50% N redxn)

- don’t want high maintenance (mechanical parts, pumping every few years)
- Wants something with low maintenance
- System that reduces volume of wastewater (smaller system, keep costs low, divert other water)
    - Could drastically reduce volume to be treated
- Considerations:
    - Change in estimates / regulations: Estimates are still based on 200 gal / bedroom
- Roger: still have to have a leach field for Presby system

Focusing on high density areas

- Composting toilet considerations: pathogens in high-density areas (Haiti example; people weren’t composting fully)

Funding

Need to consider the *true value* of a system; could be delayed; slow return on investment

- Beneficiary of true value could be 40 years down the line; should be willing to pay for investment
- Willingness to pay: other costs (cutting into ag production, etc)

Timelines! Must consider the timeline of benefits and costs

Somebody has to give $ up front; County has to be willing to go in and pay for it (in discussion of decentralized systems)

Connecting to decentralized system would require establishing easement

Need to find vacant area to put system in; need 100% buy-in

Construction to connect to system covered by… ? (? State clean water act?)

Notes – Kula workshop

3/12/19 Group: Kirsten

Minimize cost

- ONE:
- Get chloramines out of drinking water if a problem
    - Issues identified: may be really expensive to fix? May not be cost effective compared to other options
- Need to really understand what the N source are → need a study
- RISK: depends on the outcome of the studies whether this minimizes risk
- EQUITY: if major issue, will spread cost across larger population inexpensively
- TWO:
- Fix the worst offending cesspools
- Improve the standards and maintenance of existing
    - This would require getting rid of the 2050 ban
- RISK: somewhat
- EQUITY: fixers pay, so others are happy unless you spread the cost across the entire community somehow
- THREE:
- Change the law banning cesspools (extend past 2050), only ban for new homes/buildings
- RISK: Poor, maintains status quo
- EQUITY: great now, but pushes onto future generations.
- FOUR:
- Innovative technology; solar-powered; fits into the cesspool hole so it fixes the hole AND doesn't dig up the yard.
- RISK: good as central treatment if tech works
- EQUITY: everybody pays themselves
- FIVE:
- community facilities district (tax for public infrastructure) – use park or community center area for treatment
- RISK: Good
- EQUITY: shared with everyone across the tax district; tax shows up on real property bill
- Issue: requires law/regulation – is this really "public infrastructure"?
-

Minimize risk to aquifer

- ONE: Build wastewater treatment plant (centralized in upcountry Maui)
    - Issues with level of treatment? What would happen with discharge? Reuse?
    - EQUITY: everyone in county would pay through taxes
    - COST: very expensive

- TWO: Ban cattle farming
    - Issues: note VERY controversial, said mainly as a hypothetical bookend. Rejected as an option for inclusion. NOT included.
- THREE:
- Fix chloramine, if needed
- Gauge for nitrogen at the household level to find worst offenders; find lava tubes

Maximize equity and fairness

- Share the cost across all users of the aquifer not just the polluters
- Have feds pay for it (EPA?)
- Increase the credit available

WINS

- Get chloramines out of the drinking water, if they are an issue. Study the impact and figure out cost-effectiveness
- Innovative technology – within cesspool? – at household level

FUNDING

- Pukalani WWTP model at Kula: serves the high density communities (Kula, Haiku, Olina, Haliimaile). Costs would be for construction of pipelines and o and m. construction could be financed via a civil improvement district. Maybe we can get the water pipes at the same time! This would be a huge incentive! Developers should pay for the pipelines. Maybe put the pipelines in the gulches, but watch out for flooding. Put the WWTP down where there is enough solar energy to run it. Then for the households NOT connected, the state/county should pay x%.

Final thoughts:

- Find common solutions – hui up households to achieve some economies of scale
- We may need regulatory change to allow households to collectively treat waste together (cross property lines)

Kula (3-12-19) Meeting Notes: MB

Overall minimum cost

Minimum cost alternative

What is the lowest cost option?

Somebody else pays?

Private investment?

State -> Maui

Fed -> State

Lorrin:

Would like to see the cost to society overall first -> then depending on that partition who pays…

Joanna:

Meg: regulatory = cheap?

New composting toilets… ?

Sean: Document listed all the technologies was very helpful – send same with cost.

Kind of left with replacing a cesspool with the cheapest unit feasible for each TMK? [that won't fail and end up needing replacing straight away]

Cost SOOO important to narrow the scope

Roger → how much is a

AVERAGE!!! Upper/ Lower/ What's likely in Maui.

Plastic tanks for $1500 but they'll fail – value and life and risk of failure are important too

Sina (wastewater branch)

In Upcountry Maui, there is a lot of soil from the ground to where the aquifer is at?

Sina is looking at the alternatives and thinking that septic + leach = most economic ?

Would that be a solution though?

There are 7000 cesspools => would centralized management be cheaper?

Can we RANK -> make a shopping list? It's not as simple as we think?

Could we weight based on what we thinking is contributing to risk?

ALTERNATIVE: FOCUS ON DENSITY!!!!

Whether it is being used is IRRELEVANT

Can't just pollute the groundwater because it might be needed – It's not PONO

In lower areas, water is already polluted because of pesticide.

IS IT FAIR?

Put aside the amines?

Let's say the cesspools are polluting downhill

Upcountry water is brought in from East Maui -> not crapping in own water? -> but influencing downhill.

Bringing water? / Don't drill? / Treat the water (activated carbon) -> it works for pesticides, but doesn't help with Nitrogen, so you would need a different type of treatment plant… it's easy to treat pineapple pesticides….

Joanna:

DON'T want to ADD

DO want to PROTECT, DO want to AVOID expense

Possible reduction in volume of groundwater – fair for future?

OUT of the BOX: -> SINA?

Looking at the sources?

?? is probably a big contributor? Source reduction? Separating what's causing the high N in the wastewater. Wastewater treatment plant?

SOURCE SEPARATION: Urine Separating Toilets!!! (70% of N is in Urine)

- ➔ **Question re: what we do with it?**

FUNDING!!!!!

The only current program for helping to fund is the tax credit program

Because priority one, everyone in Upcountry qualifies!!

Tax credit for the WHOLE amount? (10,000 is under the cost)

There is also a cap on the total amount:

- ➔ **Only 2500 cesspools that could be closed -> this is way not enough**
- ➔ **Low or no interest loan program!! (like the solar panels in oz)**

- **If you could pay back the loan on a 25000 septic tank installation over 25 years, its similar to a monthly sewer bill with a base charge + gallon charge**
- **Average 600g / day…**

➔ **Can you have people be responsible, but make it easier to pay!!!!!**

Environmental loan programs?

Clean water state revolving fund loans program.

Is available for providing low interest loans to homeowners… but not able to do broad scale for loads of homeowners

What about a water loans program? Needs a supporting financial support system.

Drinking water -> 15% set aside for local projects, has been used in the past in places where wells are -> Joanna is open to ideas, but needs to know priorities.

Costs other than $$? Other considerations… ??

Cost reduction: SERIOUS LOOK AT COMPOSTING TOILETS/ WATERLESS SOURCES!!!

➔ **Grey water management?!! Outside the box!!! So good!!**
➔ **Could be the best!**
➔ **Would need to change the grey water rules!**
➔ **Composting toilets need work?**
  - **Maintenance cost?**
  - **Auditing and monitoring needs and requirements**
  - **Health risks, and infectious diseases, especially in high density areas**
  - **Lorrin has read a bunch of info about Haiti**
  - **Berkley has a microchip**
  - **RISK: Pathogens were recorded especially if people didn't let it**

➔ **Main N in grey water are shampoos and stuff**

- **What about a shampoo regulation?**
- **Your stuff goes on your land – instead of elsewhere.**
- **Send laundry to the plants**

Sina:

Likes systems that are PASSIVE – Presby system?

Equivalent to NSF40

Low cost for O&M??

Divert laundry away from individual wastewater -> only put water from kitchen (black water) and toilet. Size system smaller would reduce costs by a lot!!! Reducing the flow by 50% could reduce the cost.

Department is open to evaluating the regulations for system sizes?

Programs care about cost-effectiveness

The true value for all of society? Are we getting ahead -> more clean water is good

When do you get the clean water -> takes 30 years -> slow return

-> TRUE VALUE

TIMELINES FOR COSTS AND BENEFITS ARE IMPORTANT

AND/OR Willingness to pay, providing it's the cheapest

Pretty

Doesn't smell bad.

Costs other than $$? Other considerations… ??

TREES -> FOOD

SMELL

SPACE

PRODUCTION

MB: suggested to the group that land footprint could be documented as a cost in the strategy evaluation.

LOW COST LOANS ARE GOOD?

Photo-voltaics?

DECENTRALISED? – can – but needs land easement and everyone has to be onboard. Would work if county did it because they can require everyone to tie in. Hard if a private company did.

In big island, the county put in a sewer line, and the properties in the zone of contribution received funds to make that connection from the drinking water.

SEWER? -> cost only, permanent commitment. Maintaining it is really expensive. Lifetime of sewer fees.

LOGISTICALLY CHALLENGING?

At the end:

Dick Mayer suggested that some common solutions might reduce costs – e.g. a 4 home treatment system, that can go across boundaries.

It was noted that to residents, some objectives are more important than others – how will we decide/ integrate the information. We will be able to say for this goal, Alt X is better than Alt Y, for this goal XXX is true. KO explained that since that is a normative value, it's not for us to decide.

____

Sharing:

I noted that KO group wanted to know the impact of Nitrates from chloramines and whether switching to something more expensive would drop the N in the system.

"It's not PONO to pollute"

KO group also suggested something like community centralized systems in high density areas, with a focus on innovative low tech, low power solutions. They liked the idea of solar panel = balance.

AF group wanted to know about regulatory reform. Wanted a focus on contributors. Also I had a note about risk mapping re: N from leachfield for each OSDS/TMK based on depath, age, lava tube…

____

Notes – Kula workshop

3/12/19

Group: Phone In (Whitney)

Bookends

What is a good option for the cost alternative (lowest cost)?

Doing nothing cheapest, but can't just pollute the groundwater because it might be needed – It's not PONO. In lower areas, water is already polluted because of pesticide, but even so, want to protect; avoid expense, avoid further polluting, not add.

Possible reduction in volume of groundwater – what is needed/fair for future?

Don't want to just buy the cheapest; could get a cheap tank, but cheap materials will fail, run risk of collapse with pumping

Septic and leach field might be the cheapest; but likely not a solution to the contamination.

There are 7000 cesspools => would centralized management be cheaper? Especially in high density areas?

Bringing water? / Don't drill? / Treat the water (activated carbon) -> it works for pesticides, but doesn't help with Nitrogen, so you would need a different type of treatment plant… it's easy to treat pineapple pesticides with a filter, but not the Nitrogen.

Alternative to see if it makes any difference:

Replace cesspool with the cheapest unit feasible for each TMK that won't fail and end up needing replacing straight away.

Alternative: Focus on High Density areas

Either sewer or decentralized systems in high density areas, definitely for new developments, and something simple, like the Presby system in other sites.

Barriers:

Connecting to decentralized system would require establishing easement

Need to find vacant area to put system in; need 100% buy-in.

Would work if county or co-ordinated it because they can require everyone to tie in. Hard if a private company did it. Iif the community all asked for it, then maybe some public land easement could be used for the site.

Somebody has to give $ up front; County has to be willing to go in and pay for it.

Sewer connection costs $: On big island, the county put in a sewer line, and the properties in the zone of contribution received funds to make the connection.

SEWER? -> permanent commitment. Maintaining it is expensive. Lifetime of sewer fees.

Alternative - Everybody wins: Low Maintenance

Something like e.g. the Presby system – Low Maintenance, reduces N; meets NSF 40, maybe even 245? (50% N redxn)

- Low maintenance. Mechanical parts, pumping every few years increase costs and reduce compliance.
- System that reduces volume of wastewater (smaller system, keep costs low, divert other water)
- Could drastically reduce volume to be treated. Reducing flow by 50% could reduce the cost.
- Considerations:
    - Change in estimates / regulations: Estimates are still based on 200 gal / bedroom
    - Leach field still required for Presby system

High Density Alternative was again suggested, could include highly effective system upgrades as a tweak

<u>Alternative - Out of the Box: What if we separated what's causing the high N in the wastewater?</u>

SERIOUS LOOK AT COMPOSTING TOILETS/ WATERLESS SOURCES

➔ Barrier: Grey water management
- Would need to change the grey water rules
- Regulation wise, you would still need an overflow leach field for the grey water for when the water isn't used

➔ Barrier:
- Composting toilets need work?
- Maintenance cost?
- Auditing and monitoring needs and requirements
- RISK: Health risks, and infectious diseases, especially in high density areas, especially if management required.

➔ Barrier:
- Social – some people don't like the smell etc.

➔ Main N in grey water are shampoos and stuff
- What about a shampoo regulation?
- Your stuff goes on your land – instead of elsewhere.
- Send laundry to plants?

➔ SOURCE SEPARATION: Urine Separating Toilets is another option (70% of N is in Urine)

<u>FUNDING</u>

Current Tax credit incentive has limitations:

- $10,000 max doesn't cover the full cost of a system → Credit for whole amount?
- Max # of available credits; statewide limit covers barely a fraction of cesspools in upcountry alone. Only 2500 cesspools that could be closed (7000 in UC Maui)
- Option that could make $ easier to bear: no / low interest loan programs
  - How does cost compare to sewer fees? Over lifetime, Monthly cost could be similar to sewage fees; what would 20 years of sewage fees look like? **If you could pay back the loan on a 25000 septic tank installation over 25 years, its similar to a monthly sewer bill with a base charge + gallon charge**

Clean Water Act loan programs; could be an underutilized source of financial assistance, but it doesn't have the capacity for broadscale loans to homewowners – not a finance institution, and bringing one in (e.g. a bank has high costs).

Drinking water fund has 15% of the total amount can be used for local projects, and has been used in the past in places where wells are, but priority locations need to be identified before this could be available in UC Maui.

Need to consider the *true value* of a system; could be delayed; slow return on investment

- Beneficiary of true value could be 40 years down the line; should be willing to pay for investment
- Willingness to pay: other costs (cutting into ag production, etc)

Timelines! Must consider the timeline of benefits and costs

Additional Notes:

Timelines for costs and benefits important, and/or willingness to pay, providing cost-effective. **For instance,** ~ 30 year delay on clean water, = slow return

Costs other than $$ to consider:

TREES -> FOOD

SMELL

SPACE

PRODUCTION

- ➔ Maybe land footprint could be documented as a cost ?

Appendix IV: Groundwater model

Groundwater and Transport Modeling

The purpose of the numerical groundwater flow and transport modeling was to test various cesspool conversion alternatives. The groundwater flow model that was used is the USGS groundwater modeling code MODFLOW 2005, an international standard for simulating groundwater flow. The model is represented by a grid of cells in three dimensions, and groundwater flow is calculated as water movement based on groundwater flow paths between adjacent cells. A modular three-dimensional multi-species transport model, MT3DMS, was used to simulate movement of nitrogen due to groundwater flow. MT3DMS uses the flow solution from MODFLOW to simulate the movement of dissolved contaminants in groundwater (Zheng and Wang 1999 and 2012). This modeling code is capable of simulating dissolved contaminant movement by advection (the movement with groundwater flow), diffusion (the movement of contamination due to a concentration gradient), and dispersion (the spreading of contamination due to multiple flow paths of differing characteristics in the aquifer). MT3DMS also simulates the reduction in dissolved contaminant mass due to processes such as decay or transformation and sorption (attachment) to the aquifer matrix (Zheng and Wang 1999 and 2012).

The model from the “Upcountry Maui Groundwater Nitrate Investigation Report, Maui, Hawaii” was used as the basis for this project, with updates based on new data and community feedback described below. Overall, data in this model were drawn from Commission on Water Resources Management (CWRM) well and pumping records, previous Source Water Assessment Program (SWAP) and onsite sewage disposal system (OSDS) models of east Maui (Whittier et al., 2004; and Whittier and El-Kadi, 2014), the USGS groundwater flow model of central and west Maui (Gingerich, 2008) and various GIS coverages from the State GIS website (http://planning.hawaii.gov/gis/download-gis-data/). Selected assumptions and components of the model are included in subsequent sections.

Updates to 2018 Groundwater Model

To improve agreement between model results and field sampling results, and in response to Upcountry Maui community concerns, the following updates have been made to the 2018 groundwater model:

- Added the Haiilimaile Wastewater Treatment Plant infiltration ponds (29 mg/L) and Pukalani Wastewater Treatment Plant infiltration beds (10 mg/L) as additional nitrogen sources.
- Increased former pineapple nitrogen source from 1.5 mg/L to 2.5 mg/L to better match the measured groundwater nitrogen values.

- Decreased Pukalani Golf Course recycled water source from 7.0 mg/L to 3.0 mg/L, based on data provided by the Pukalani Golf Course and Pukalani Wastewater Treatment Plant (WWTP).
- Added nitrogen source from golf courses without recycled water application (1.5 mg/L).
- Increased naturally occurring nitrogen in soil from 0.3 mg/L to 0.5 mg/L.
- The resolution of the recharge coverage was revised so the largest recharge polygon no larger than a square 300 m on each side. In many cases, the square is sub-divided where there is a transition to difference N source types.
- Updated the groundwater recharge to reflect the latest data released by the USGS (Johnson 2016).
- Based on a literature review, the percentages of nitrogen removal rates of OSDS Classes I (any system receiving soil treatment), II (septic tank to seepage pit), and III (aerobic treatment unit to seepage pit) have also been revised: Class I has a removal rate of 47%, Class II has a removal rate of 10%, and Class III has a removal rate of 20%.

Nutrient transport modeling

The distribution of nitrate in groundwater was simulated using the transport code MT3DMS (Zheng & Wang, 1999; and Zheng, 2010). The various forms of nitrogen in wastewater are converted to nitrate in the upper layers of the soil by aerobic nitrification, resulting in nitrate as the stable end species, as shown in Figure AP4-1. Nitrate remains the stable form of nitrogen under oxidizing conditions, as it is travels vertically through the vadose zone to groundwater, and then follows groundwater paths to the receiving body of water. Therefore, the transport model focuses on simulating nitrate. The model was also run with a 50-year simulation to allow nitrate to reach steady-state.

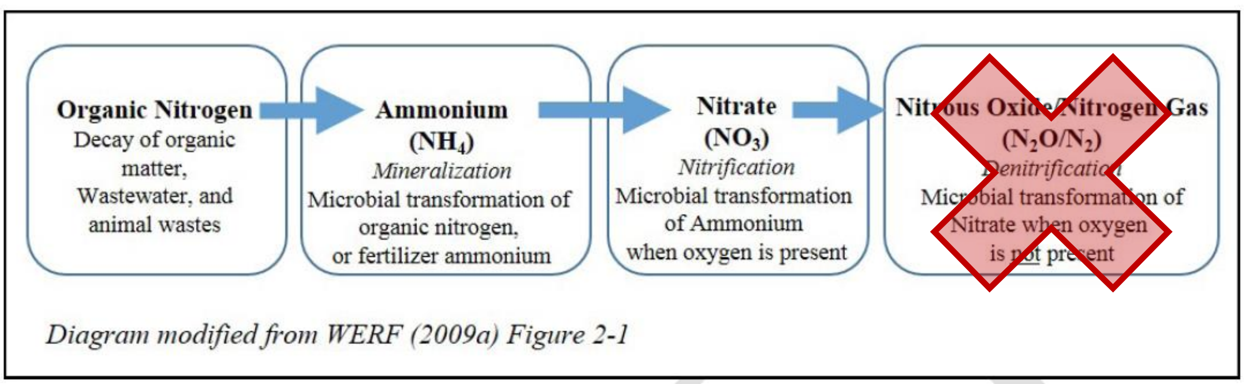

Figure AP4-1 Chemical transformation of organic nitrogen

The primary sources of nitrate modeled are listed below. AP4-1 lists the source concentrations used for the model and the basis for the values selected. Figures AP4-2, AP4-3, and AP4-4 illustrate the locations of the various sources.

- Legacy fertilizer leached from former sugar cane and pineapple cultivation

- Onsite sewage disposal leachate
- Application of recycled wastewater at Pukalani Golf Course
- Fertilizer at golf courses not using recycled wastewater
- Leachate from Haiilimaile Wastewater Treatment Plant infiltration ponds and Pukalani Wastewater Treatment Plant infiltration bed
- Natural/background levels (including ranchlands).

Table AP4-1: Nitrate Sources and Basis for Modeled Concentrations (mg/L)

Nitrogen Source	Nitrogen Concentration (mg/L)	Basis
OSDS		Effluent rate assumed 70 gal/day/person, 1.5 persons per bedroom (USEPA 2002).
Cesspool (Class IV)	87	Based on household effluent concentrations (WERF 2007).
Septic to Seepage Pit (Class II)	58	Assumes 33% nitrogen removal rate in septic tank (WERF 2009).
Septic to Soil Treatment (Class I)	34	Assumes 41% nitrogen removal rate in soil (Tasato and Dugan 1980)
Historical Pineapple	2.5	Calibrated to simulate concentrations in wells located in or near former pineapple fields.
Historical Sugar Cane	5.0	Calibrated to concentrations in groundwater beneath former sugar cane fields as indicated by concentrations in Consolidated Maintenance Base Yard Wells.
Pukalani Golf Course Recycle Water	3.0	Accounts for golf course fertilizer and additional nitrogen in recycled water. Includes application and leaching data from golf course.
Golf Course (recycled water not applied)	1.5	Accounts for golf course fertilizer and assumptions for application and leaching rates.
Haliimaile Wastewater Treatment Plant infiltration ponds	29	Based on infiltration rate and cesspool level of treatment.
Pukalani Wastewater Treatment Plant infiltration bed	10	Based on nitrate test results of effluent from Pukalani Wastewater Treatment Plant.
Natural/Background (including	0.5	Approximate average value for wells

ranchlands)		for groundwater with no anthropogenic influence.

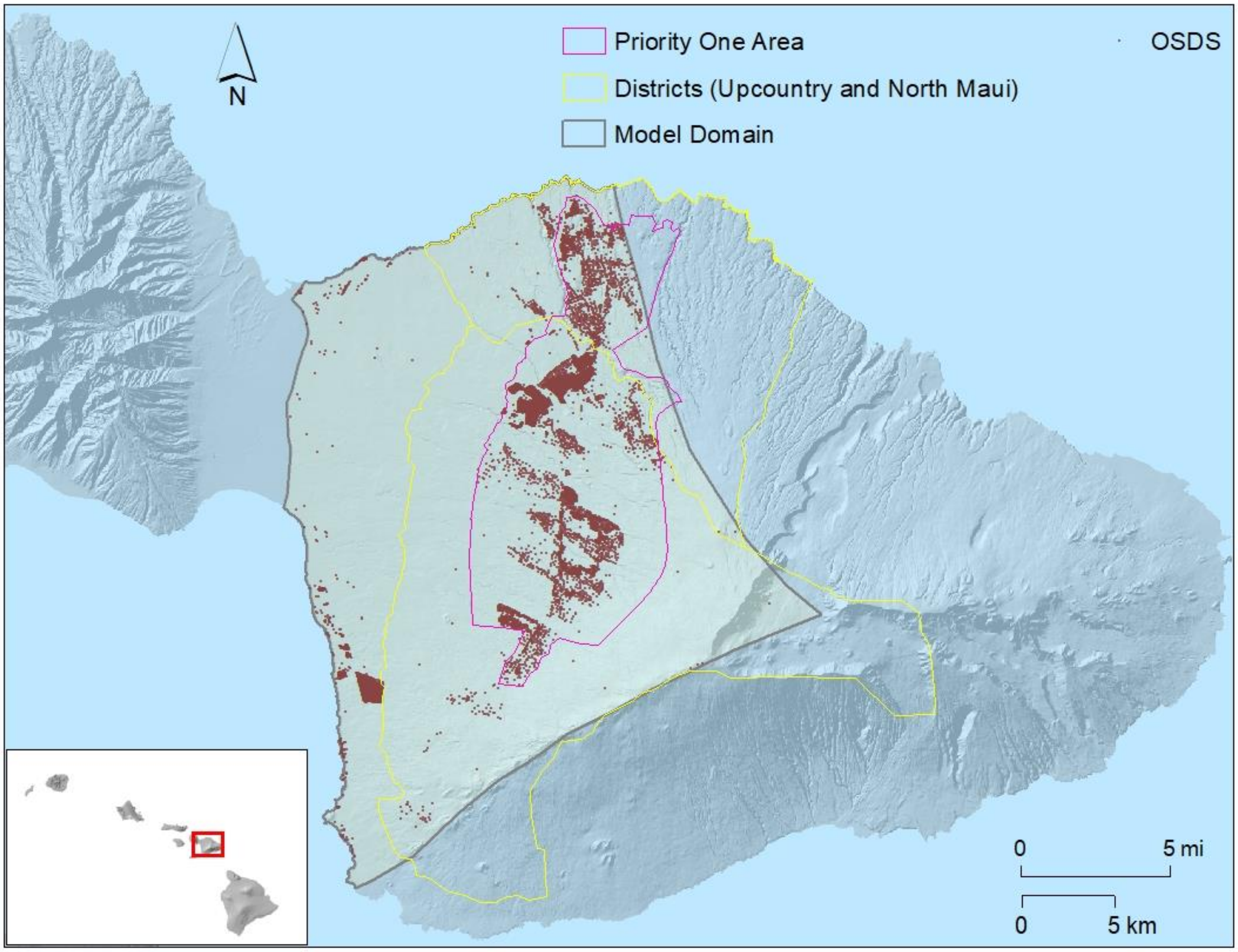

Figure AP4-2. Groundwater model domain and locations of OSDSs

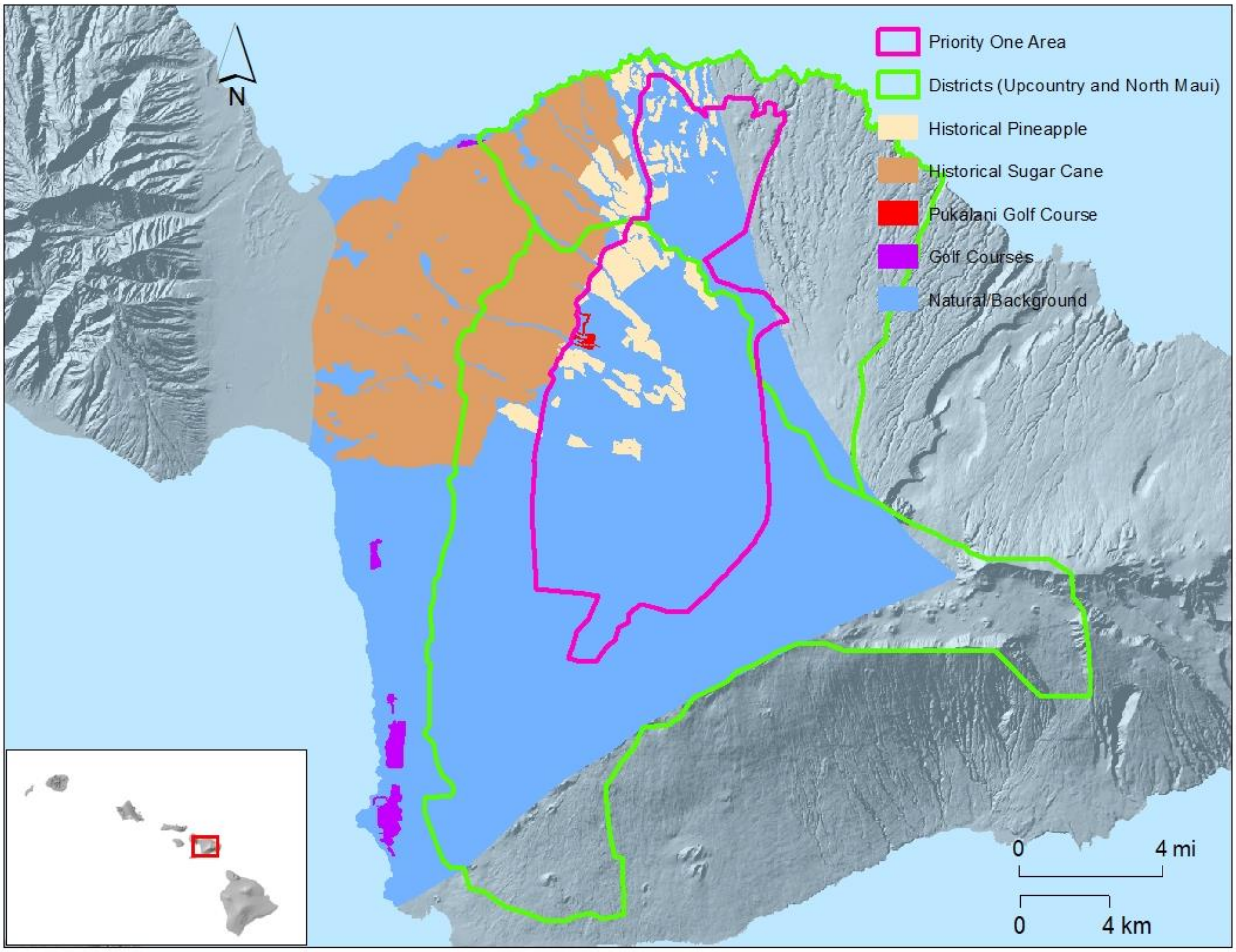

Figure AP4-3. Groundwater model domain and locations of historical pineapple, historical sugar cane, Pukalani Golf Course, golf courses (without application of recycled water), and natural nitrate sources

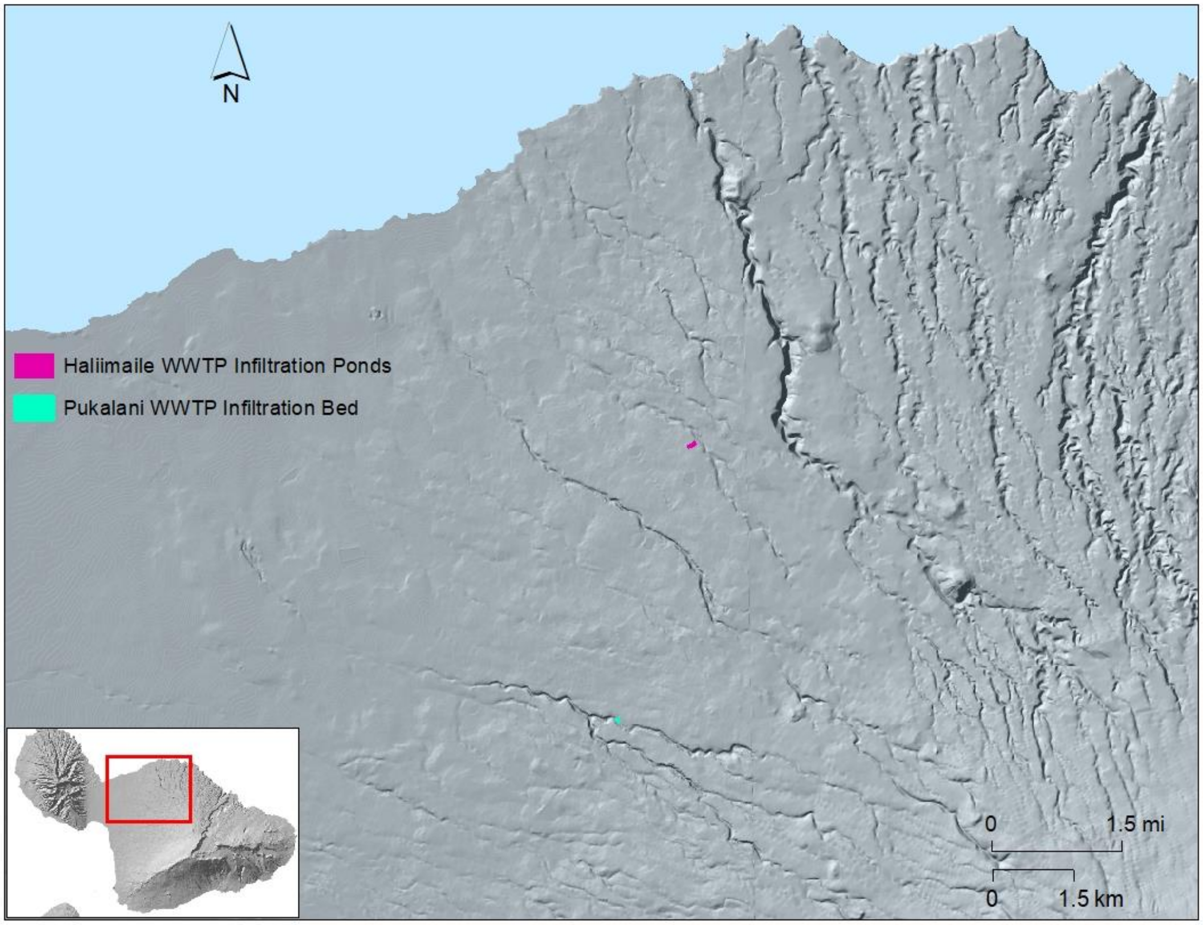

Figure AP4-4. Groundwater model domain and locations of Haliimaile and Pukalani wastewater treatment infiltration ponds and bed

Appendix V - Areas with greater than 5 and 10 Milligrams per Liter (mg/L) Nitrate Concentrations for each Alternative

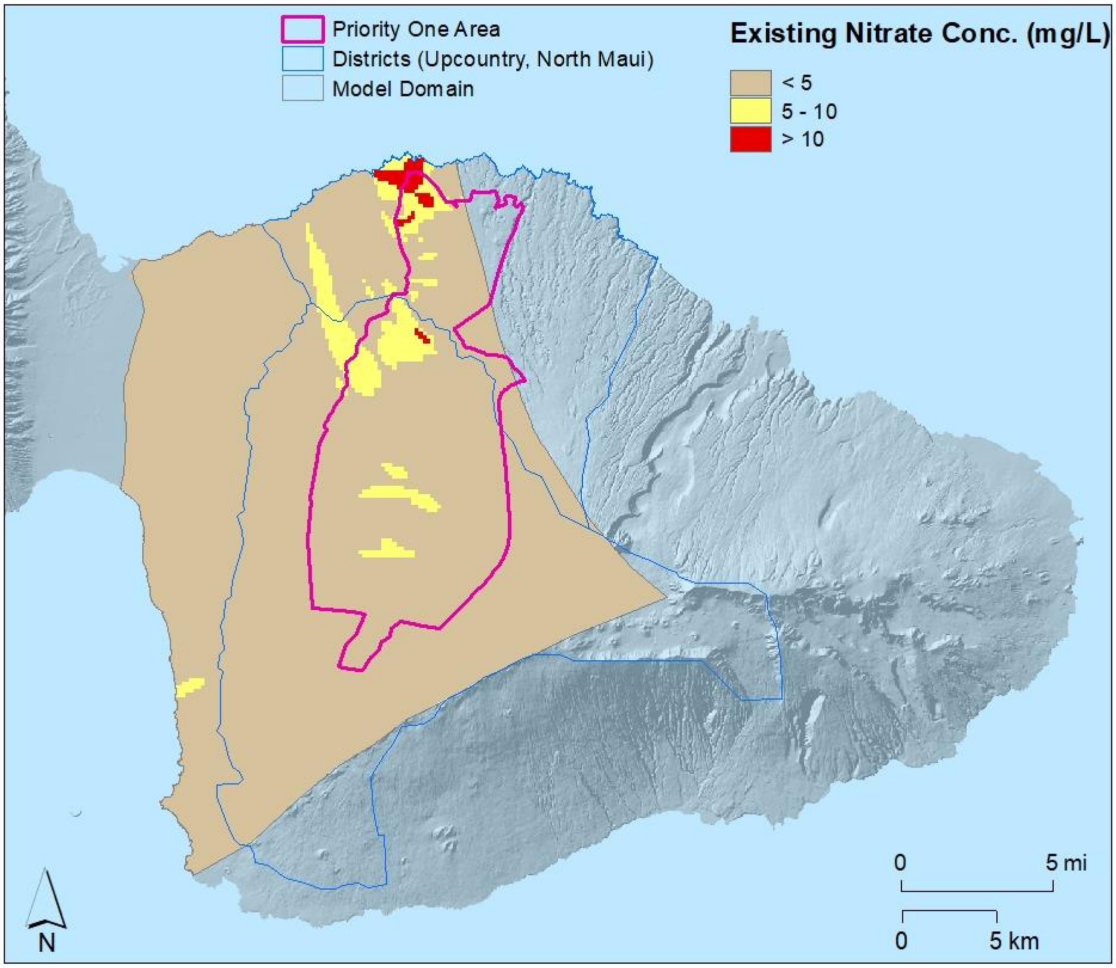

Figure AP5-1. Existing Nitrate Concentrations of Base Model

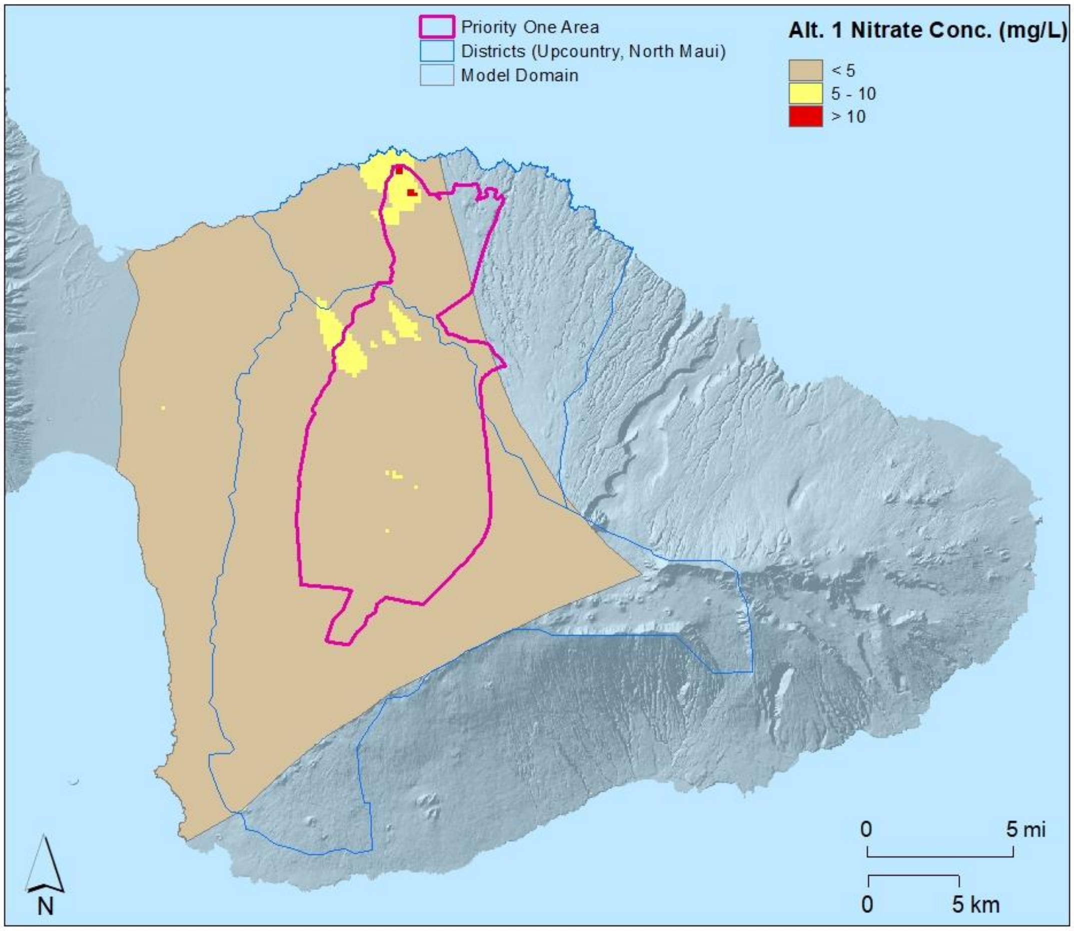

Figure AP5-2. Nitrate Concentrations of Alternative 1: Cesspools Upgrade to Septic Tank to Absorption System and Alternative 4: Cesspools Upgrade to Septic Tank to Recirculating Sand Filter to Seepage Pit. These results are equal because tax map keys (TMKs) where absorption systems are not feasible, seepage pits are allowed. TMKs where absorption systems are feasible, seepage pits are not allowed.

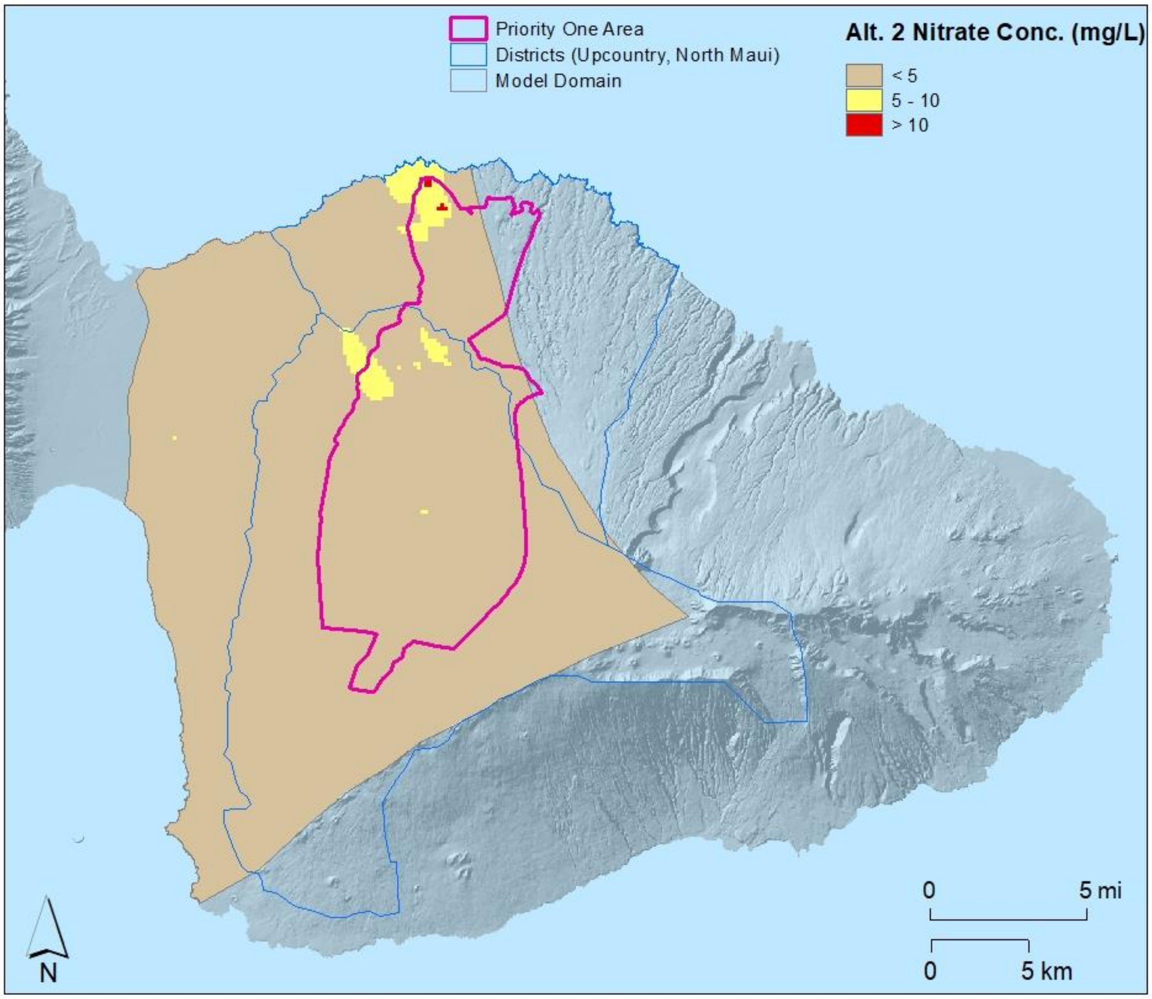

Figure AP5-3. Nitrate Concentrations of Alternative 2: Cesspools Upgrade to Septic Tank to Constructed Wetland

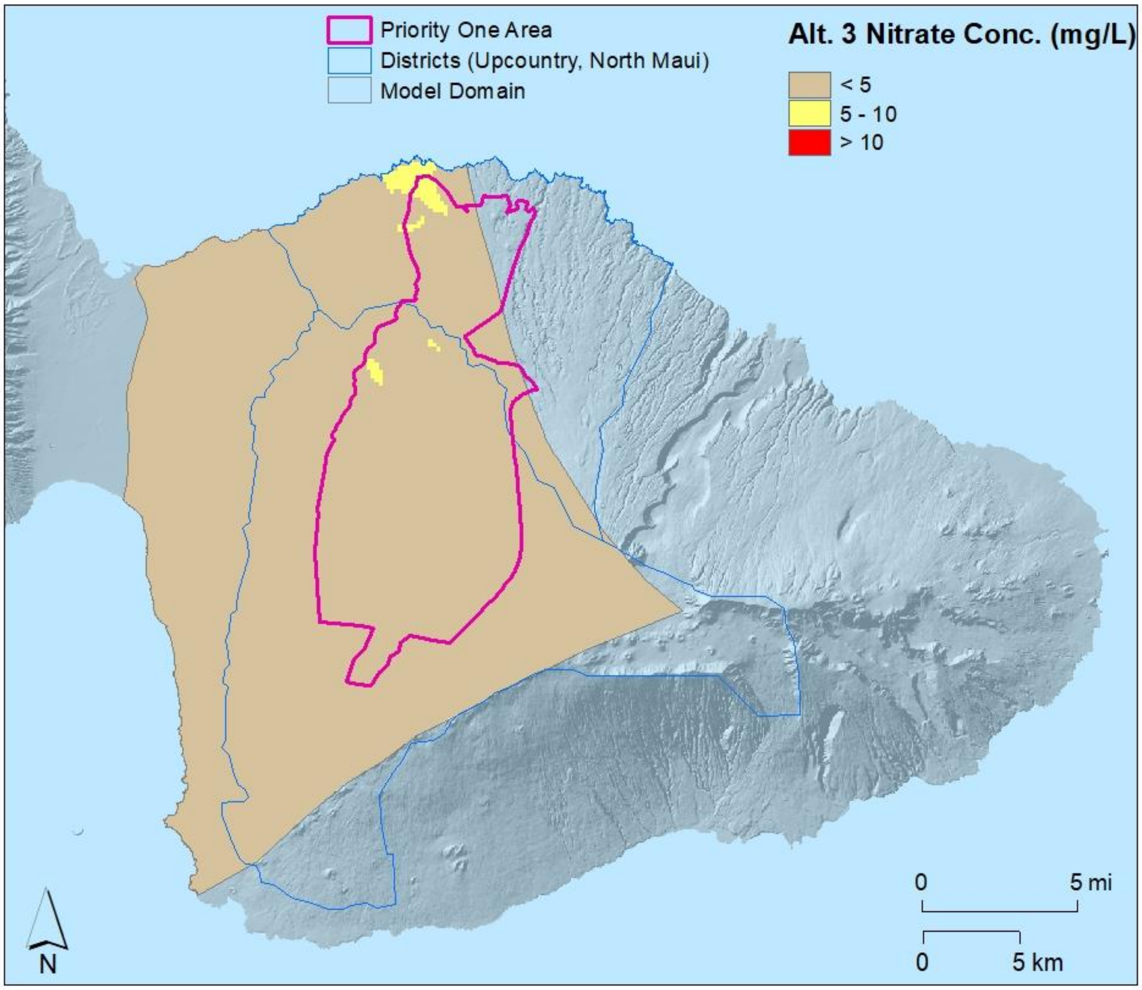

Figure AP5-4. Nitrate Concentrations of Alternative 3: Cesspools Upgrade to Septic Tank to Recirculating Sand Filter to Drip Irrigation

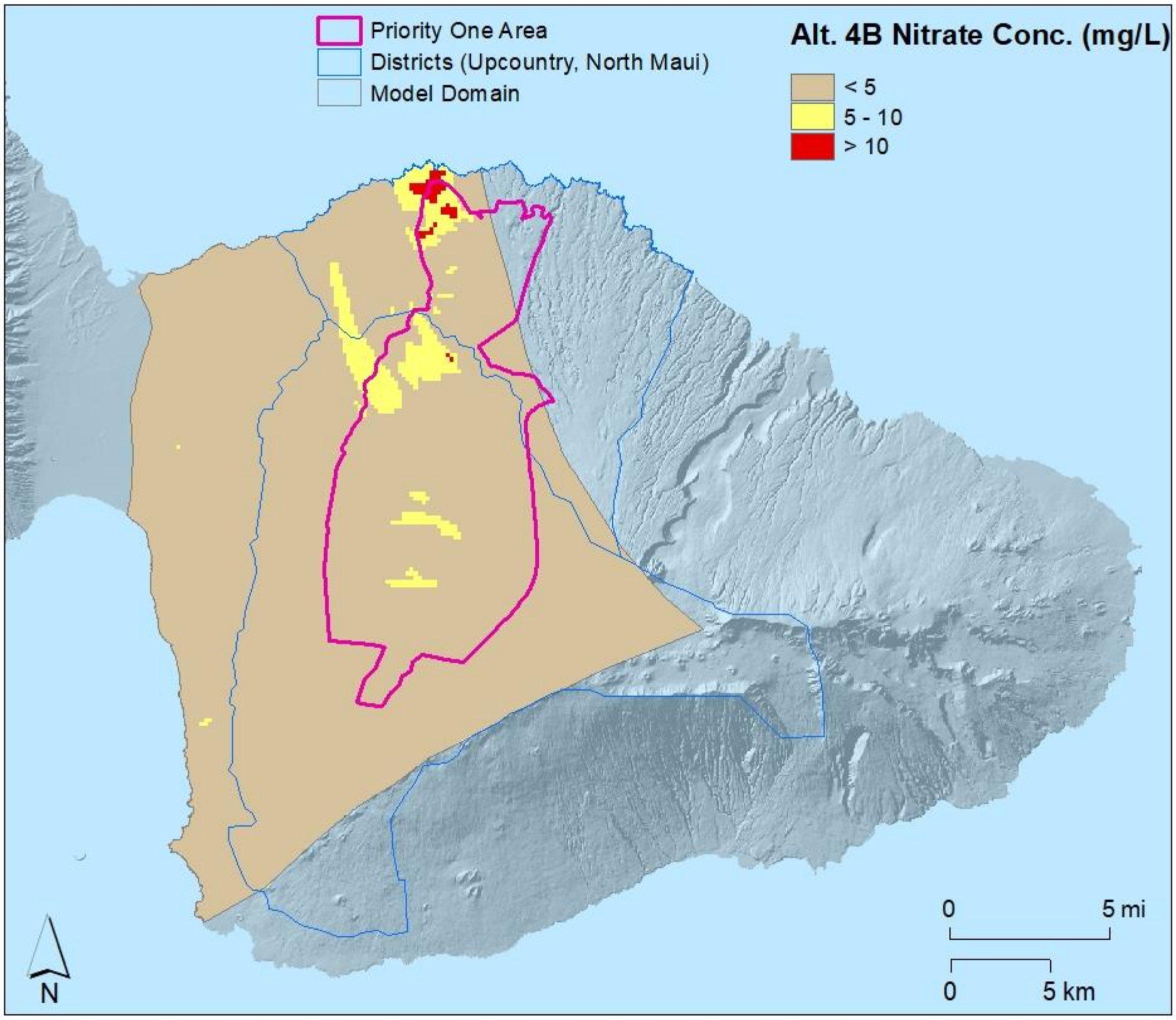

Figure AP5-5a. Nitrate Concentrations of Alternative 4B: Cesspools Upgrade to Septic Tank to Seepage Pit with calibrated loading (1.5 persons/BR and 70 gal/person)

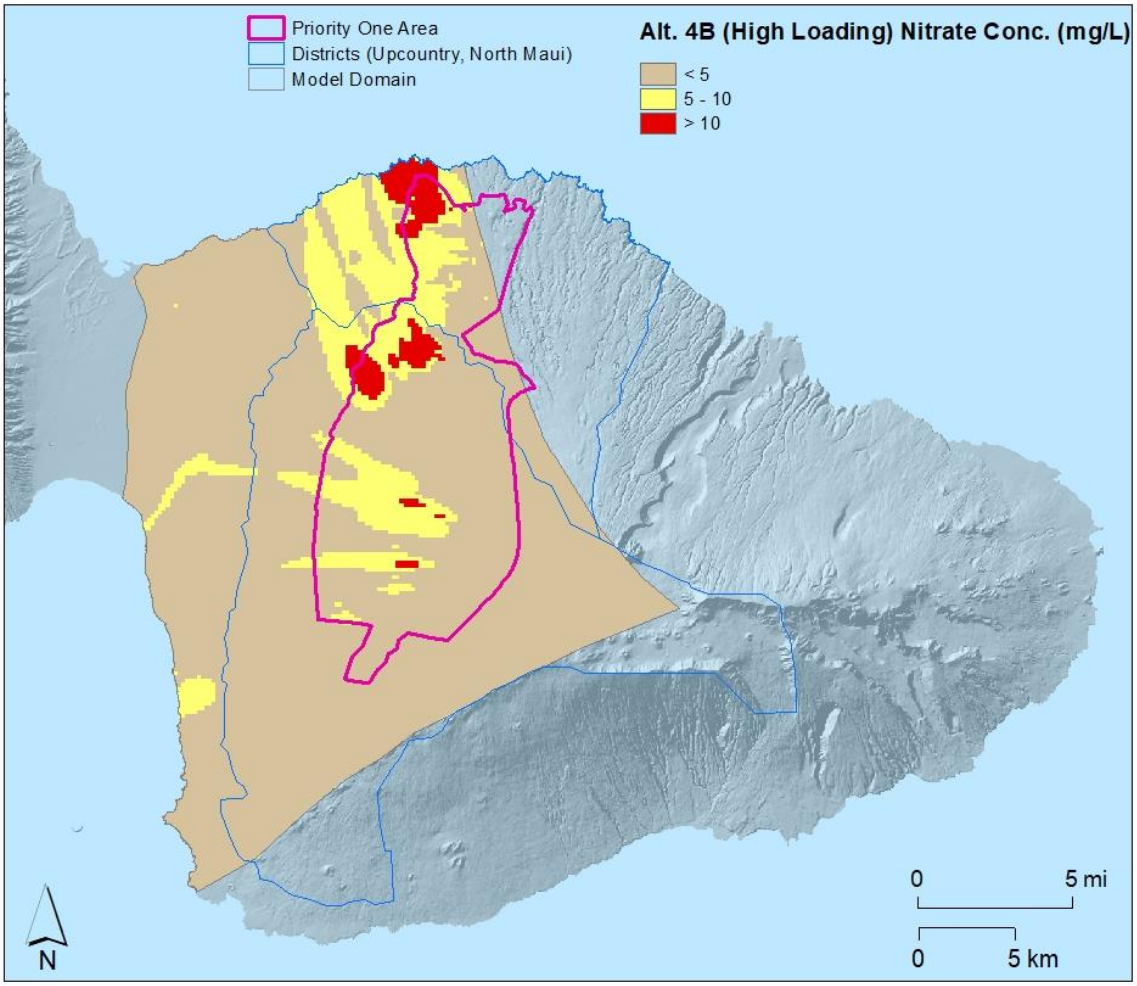

Figure AP5-5b. Nitrate Concentrations of Alternative 4B_HI: Cesspools Upgrade to Septic Tank to Seepage Pit with higher loading (2 persons/BR and 100 gal/person)

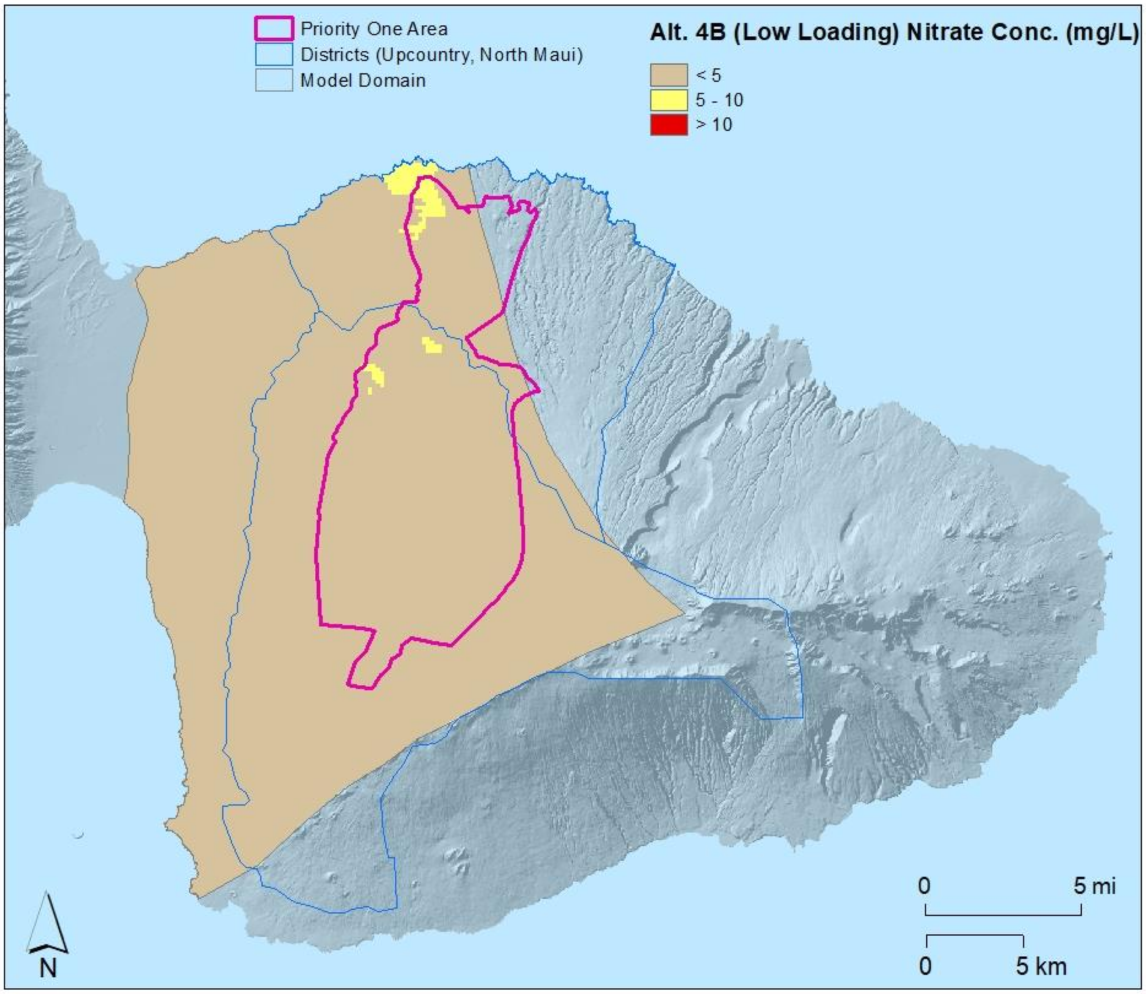

Figure AP5-5c. Nitrate Concentrations of Alternative 4B_LO: Cesspools Upgrade to Septic Tank to Seepage Pit with lower loading (1 persons/BR and 70 gal/person)

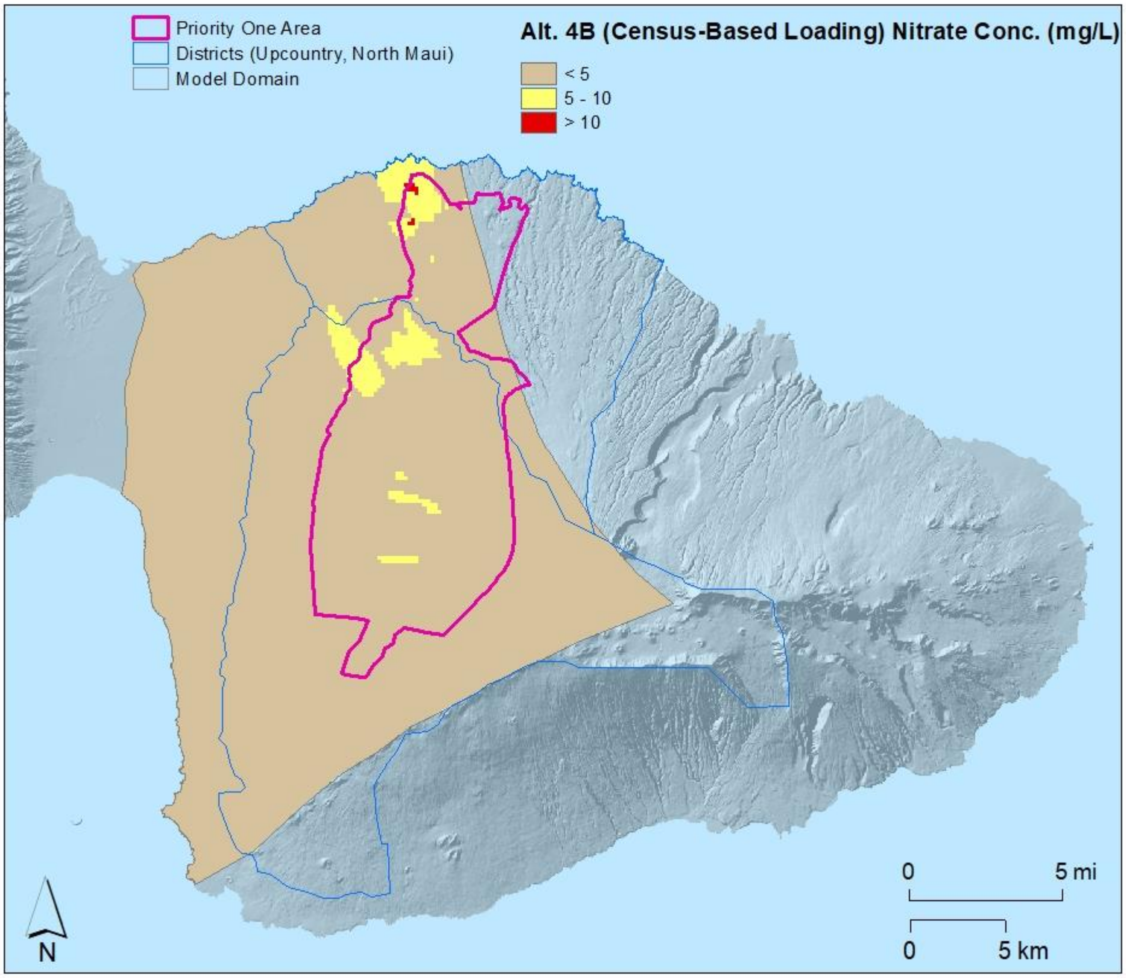

Figure AP5-5d. Nitrate Concentrations of Alternative 4B_Census: Cesspools Upgrade to Septic Tank to Seepage Pit with 2010 Census-based loading (1 persons/BR and 70 gal/person)

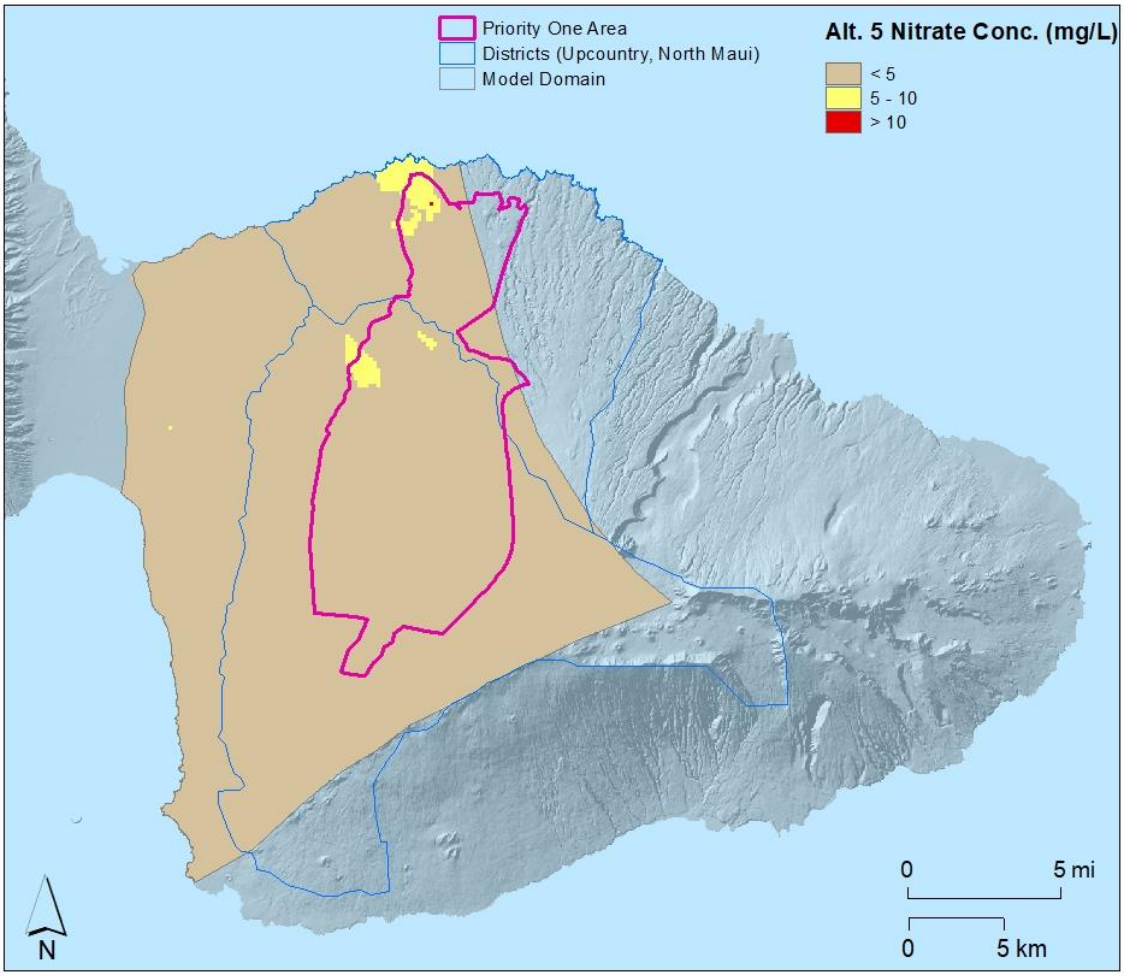

Figure AP5-6. Nitrate Concentrations of Alternative 5: Cesspools Upgrade to Septic Tank to Eliminite to Absorption System

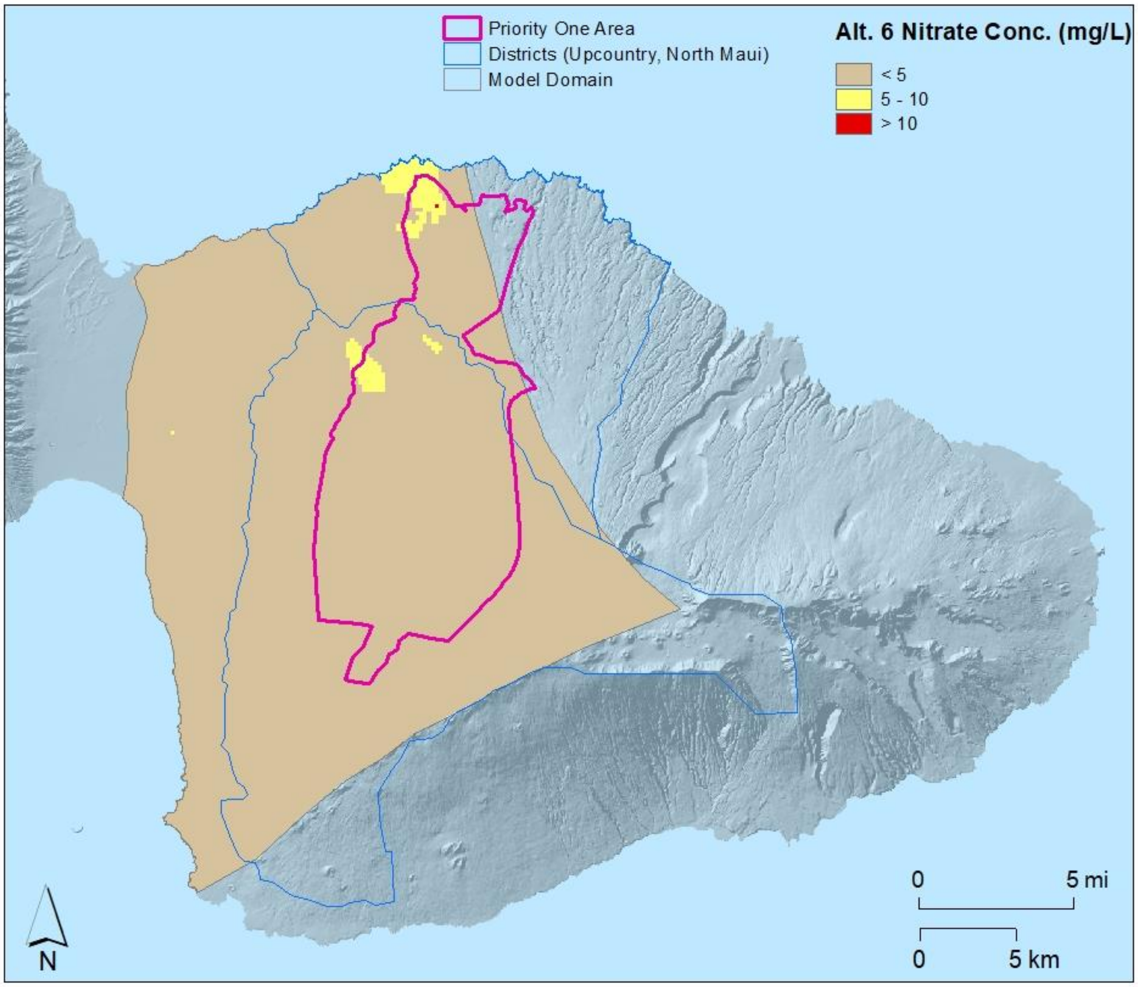

Figure AP5-7. Nitrate Concentrations of Alternative 6: Cesspools Upgrade to Septic Tank to Presby

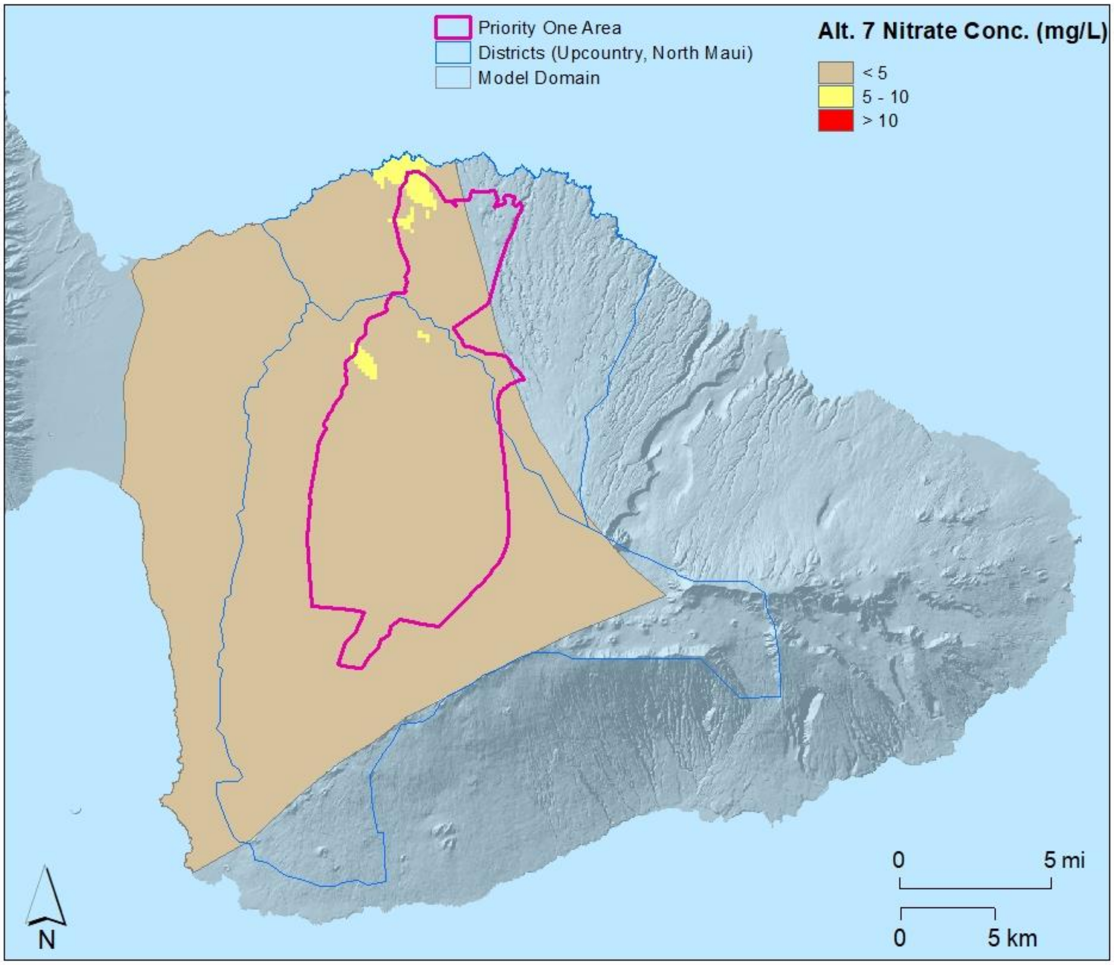

Figure AP5-8. Nitrate Concentrations of Alternative 7: Cesspools Upgrade to Septic Tank to NITREX to Absorption System

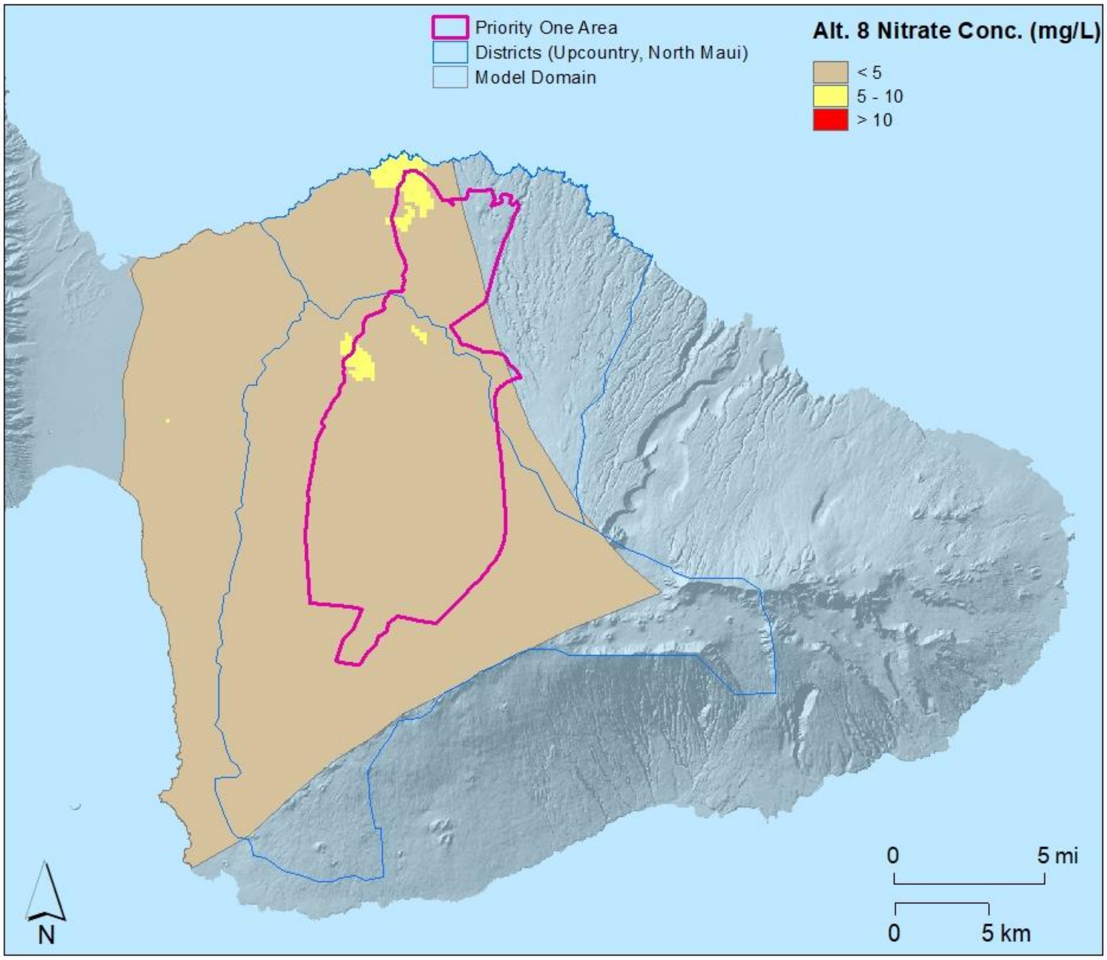

Figure AP5-9. Nitrate Concentrations of Alternative 8: Cesspools Upgrade to Septic Tank to Recirculating Gravel Filter System to Absorption System

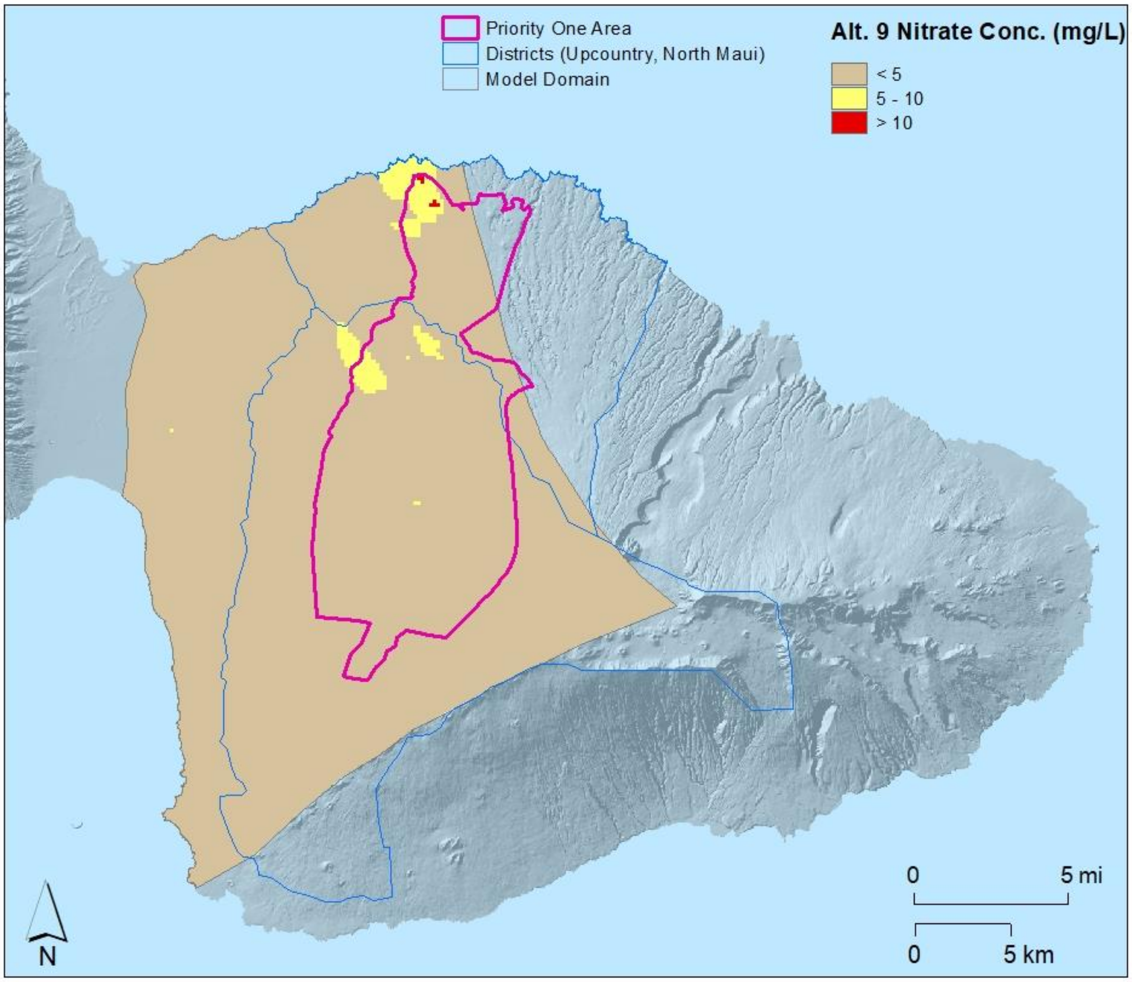

Figure AP5-10. Nitrate Concentrations of Alternative 9: Cesspools Upgrade to Septic Tank to "Layer Cake"

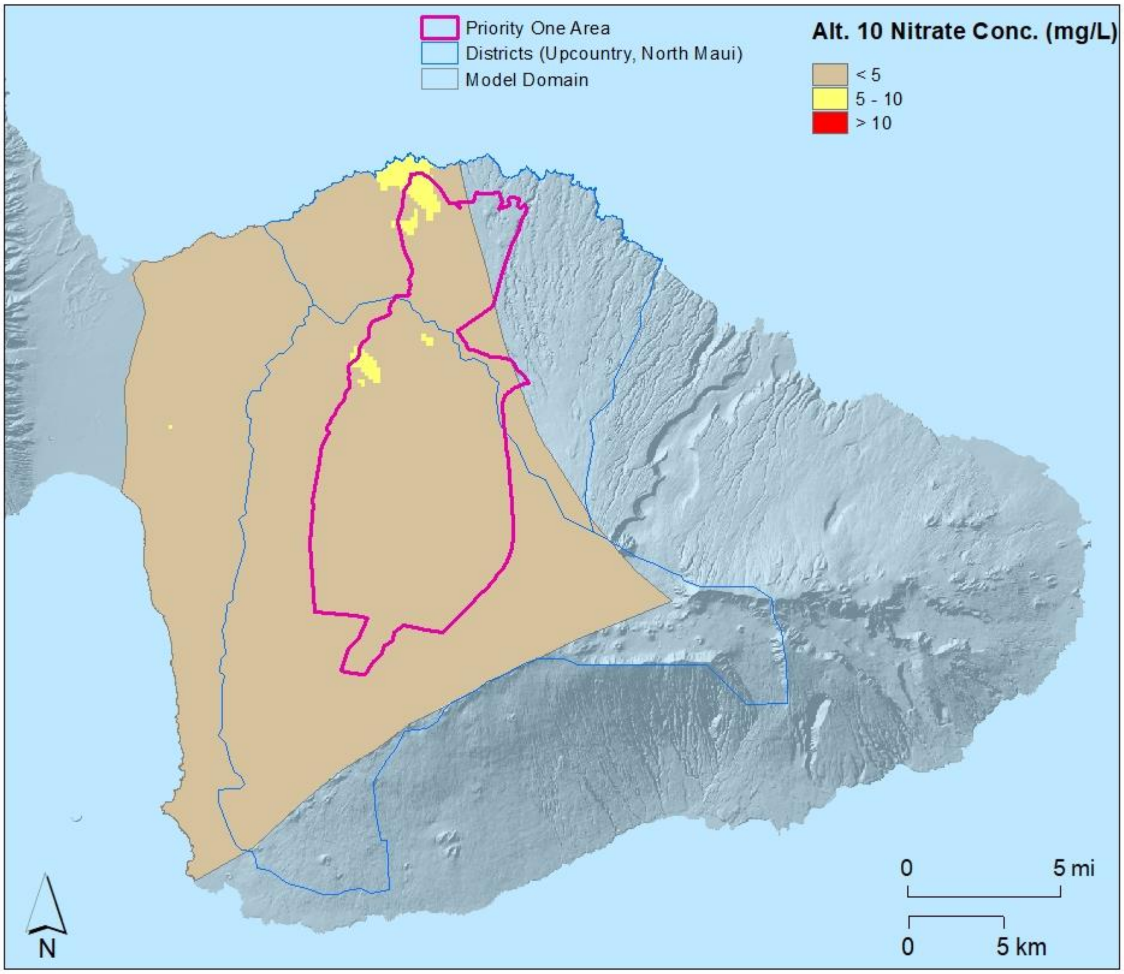

Figure AP5-11. Nitrate Concentrations of Alternative 10: Cesspools Upgrade to Septic Tank to Lined/Sequence Nitrification/Denitrification Biofilter

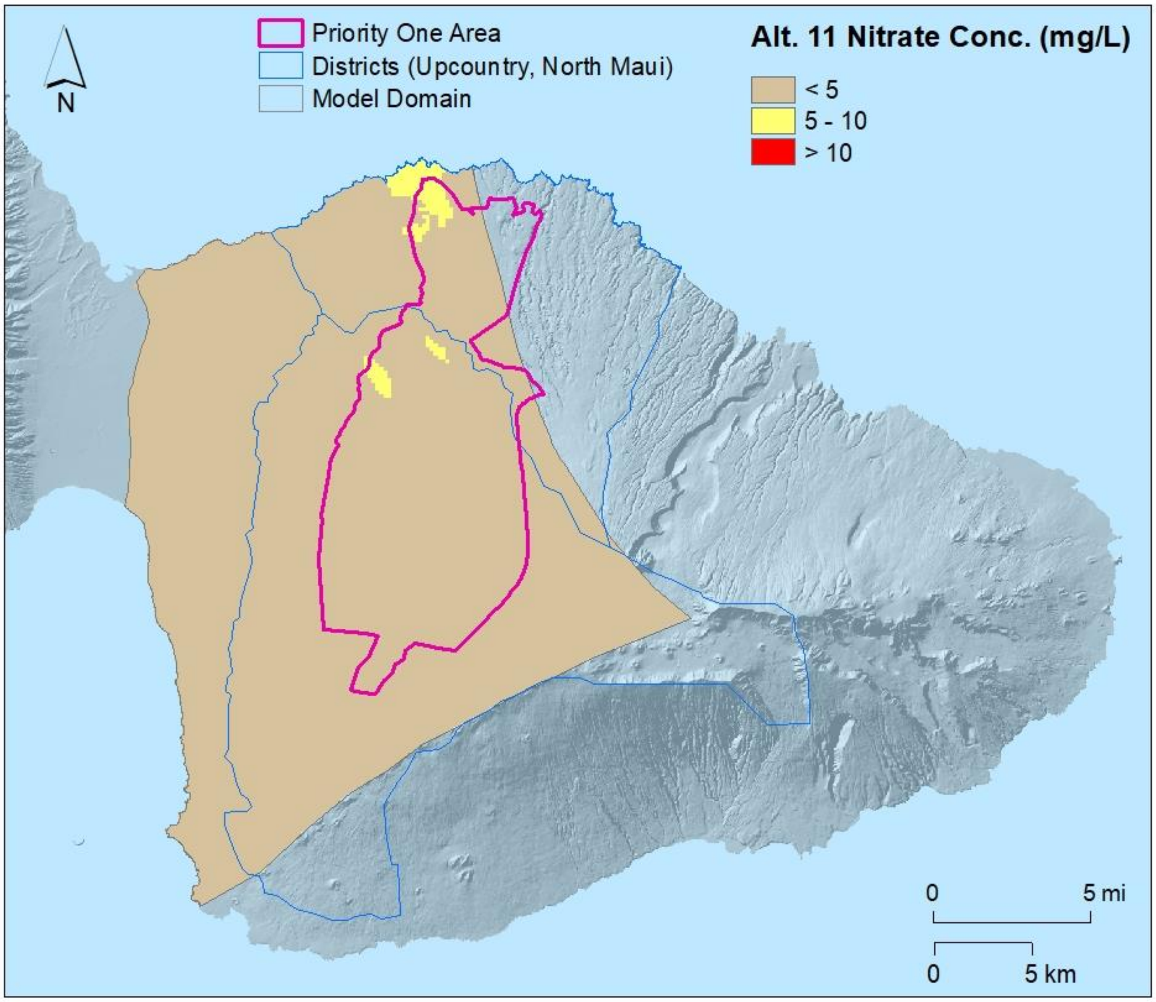

Figure AP5-12. Nitrate Concentrations of Alternative 11: Cesspools Upgrade to Aerobic Treatment Unit-Nitrification to Absorption System

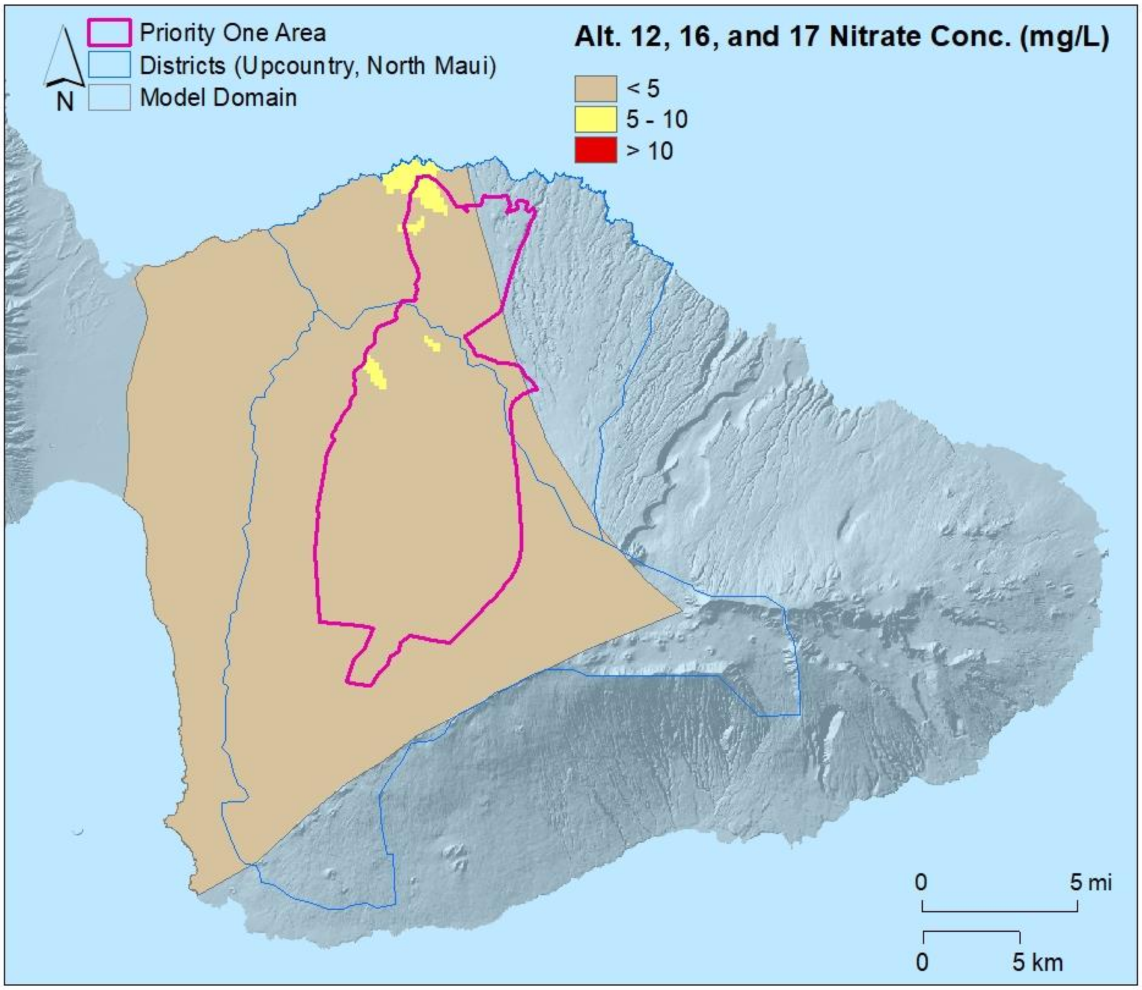

Figure AP5-13. Nitrate Concentrations of Alternative 12: Cesspools Upgrade to Aerobic Treatment Unit-Nitrification/Denitrification to Absorption System, Alternative 16: Cesspools Upgrade to Aerobic Treatment Unit-Nitrification/Denitrification to Disinfection to Seepage Pit, and Alternative 17: Cesspools Upgrade to Septic Tank to Passive Florida Units (medium, in ground). Alternatives 12 and 17 are equal because the nitrate reductions and feasibility constraints for Aerobic Treatment Unit-Nitrification/Denitrification and passive Florida units (medium, in ground) are the same. Alternatives 12 and 16 are the same because TMKs where absorption systems are not feasible, seepage pits are allowed; and TMKs where absorption systems are feasible, seepage pits are not allowed.

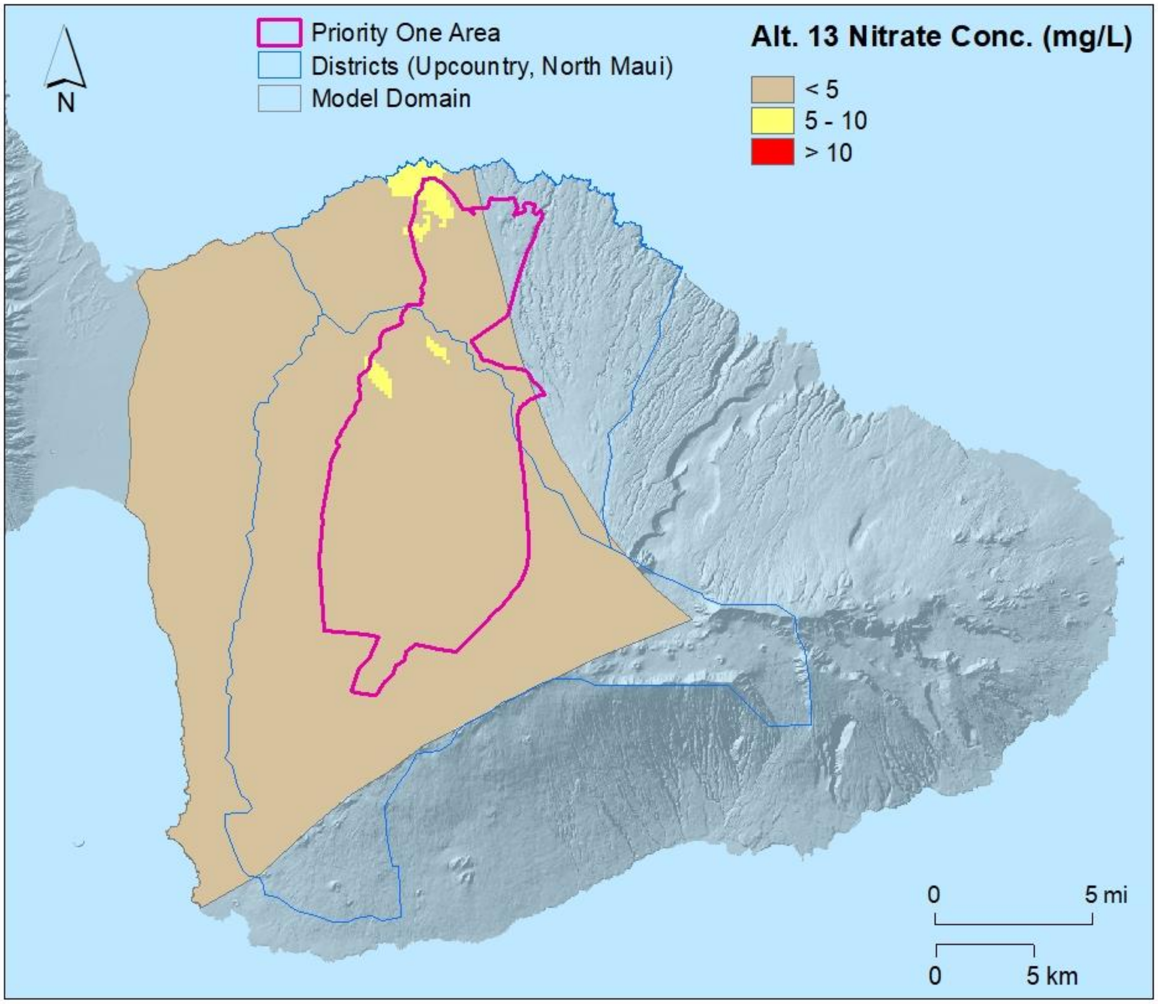

Figure AP5-14. Nitrate Concentrations of Alternative 13: Cesspools Upgrade to Aerobic Treatment Unit-Nitrification to Constructed Wetland

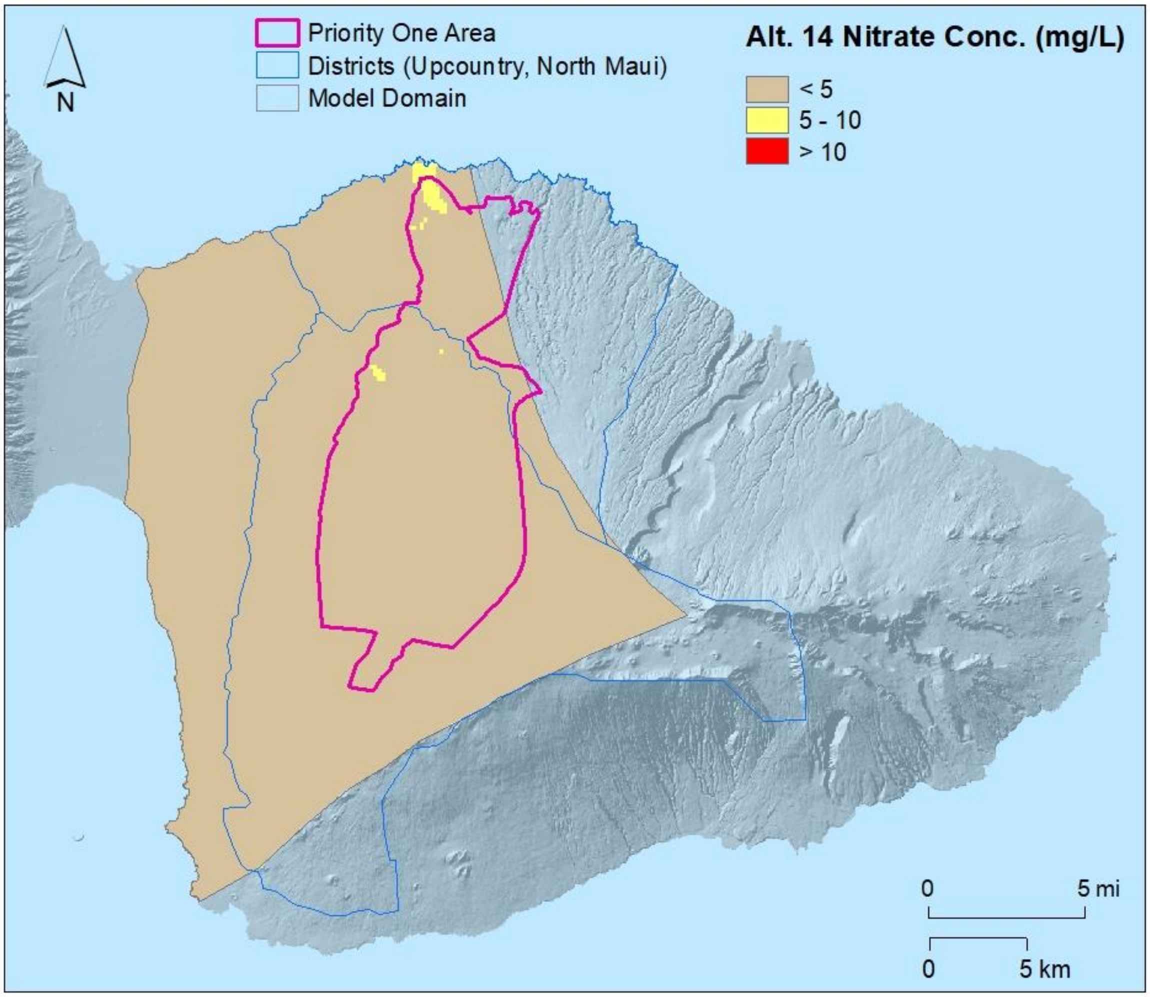

Figure AP5-15. Nitrate Concentrations of Alternative 14: Cesspools Upgrade to Aerobic Treatment Unit-Nitrification to Evapotranspiration

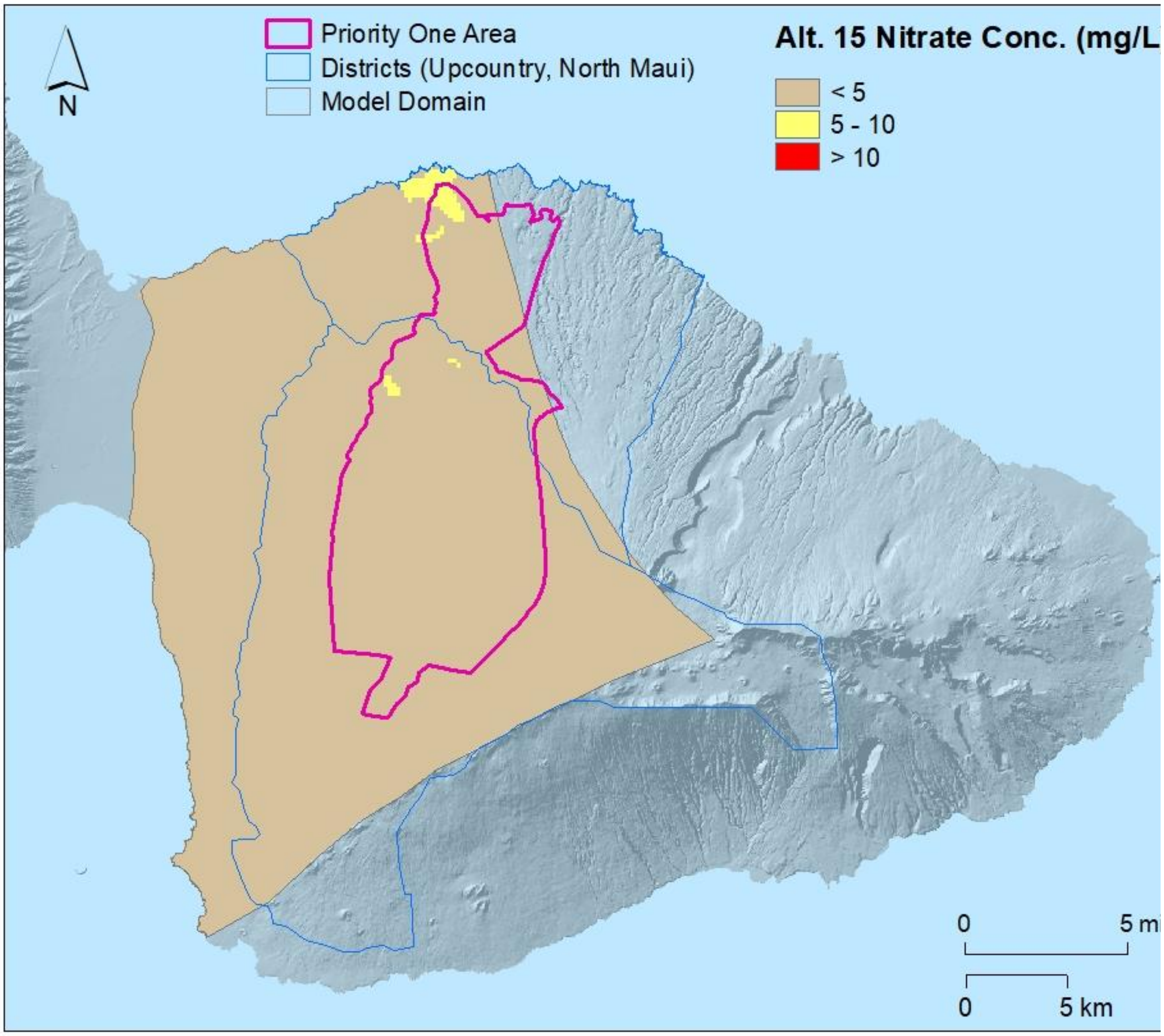

Figure AP5-16. Nitrate Concentrations of Alternative 15: Cesspools Upgrade to Aerobic Treatment Unit-Nitrification to Disinfection to Drip Irrigation

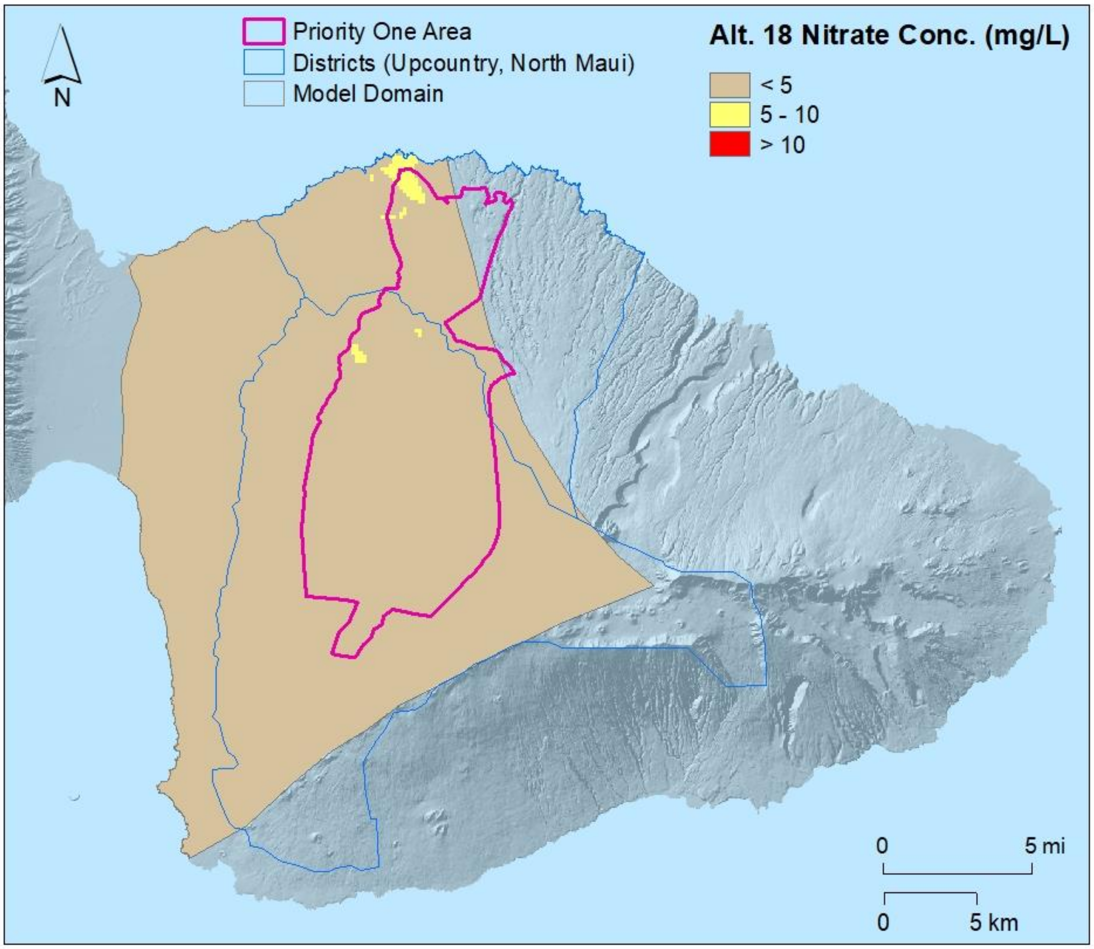

Figure AP5-176. Nitrate Concentrations of Alternative 18: Cesspools Upgrade to Septic Tank to Passive Florida Units (high) to Absorption System

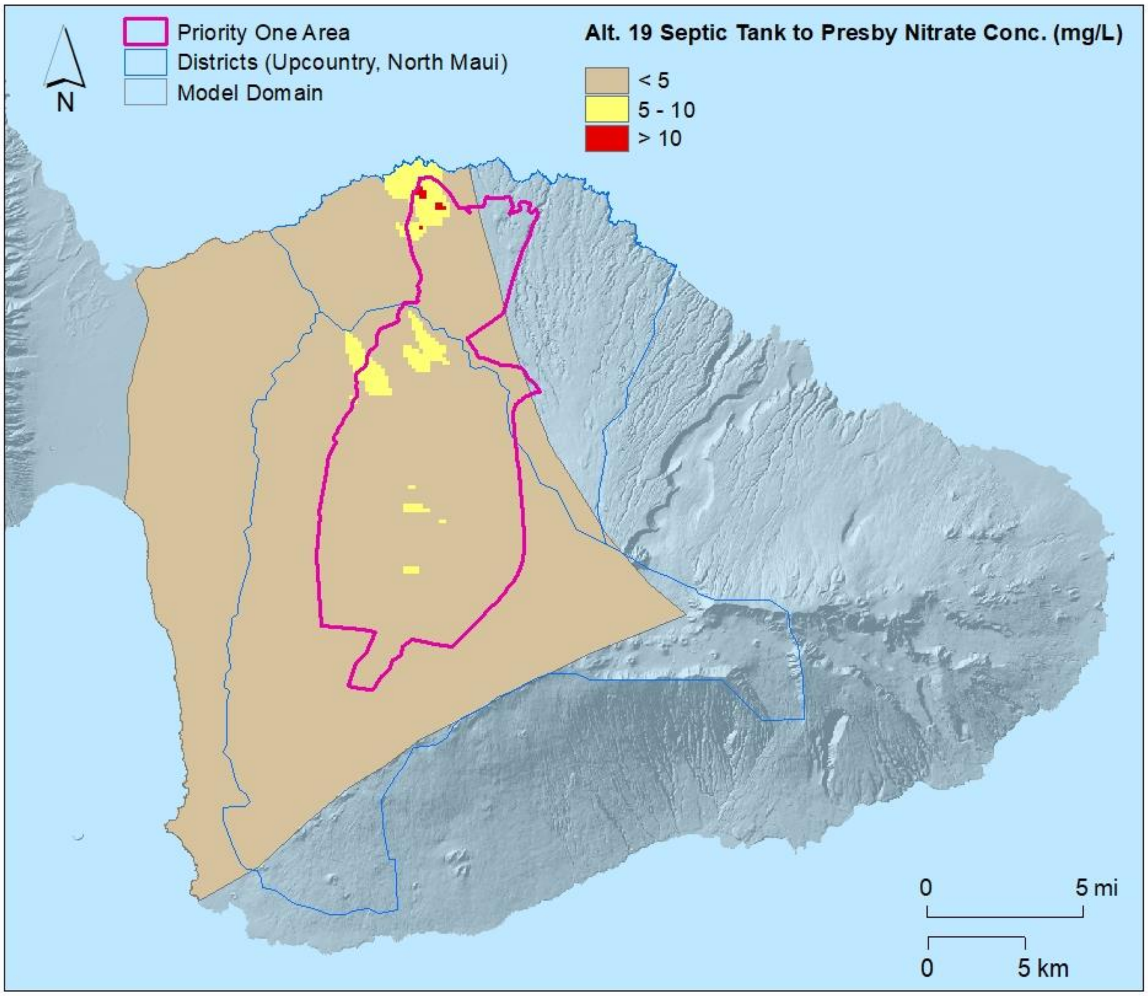

Figure AP5-18. Nitrate Concentrations of Alternative 19A: 22% Top Contributors Upgrade to Septic Tank to Presby (highest mass reduction in alternatives 1-18)

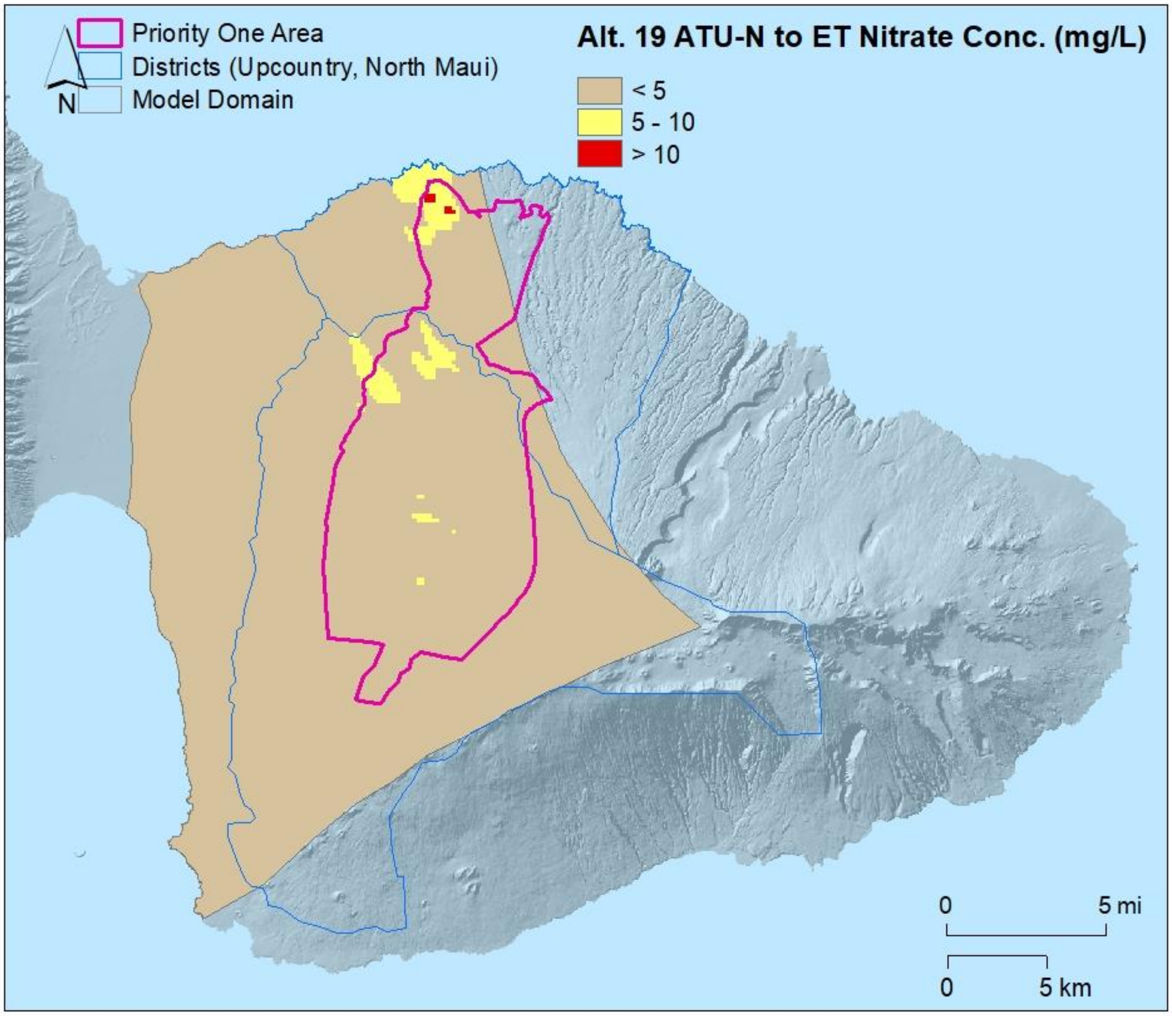

Figure AP5-19. Nitrate Concentrations of Alternative 19B: 22% Top Contributors Upgrade to Aerobic Treatment Unit-Nitrification to Evapotranspiration: (smallest area >5 mg/L in alternatives 1-18)

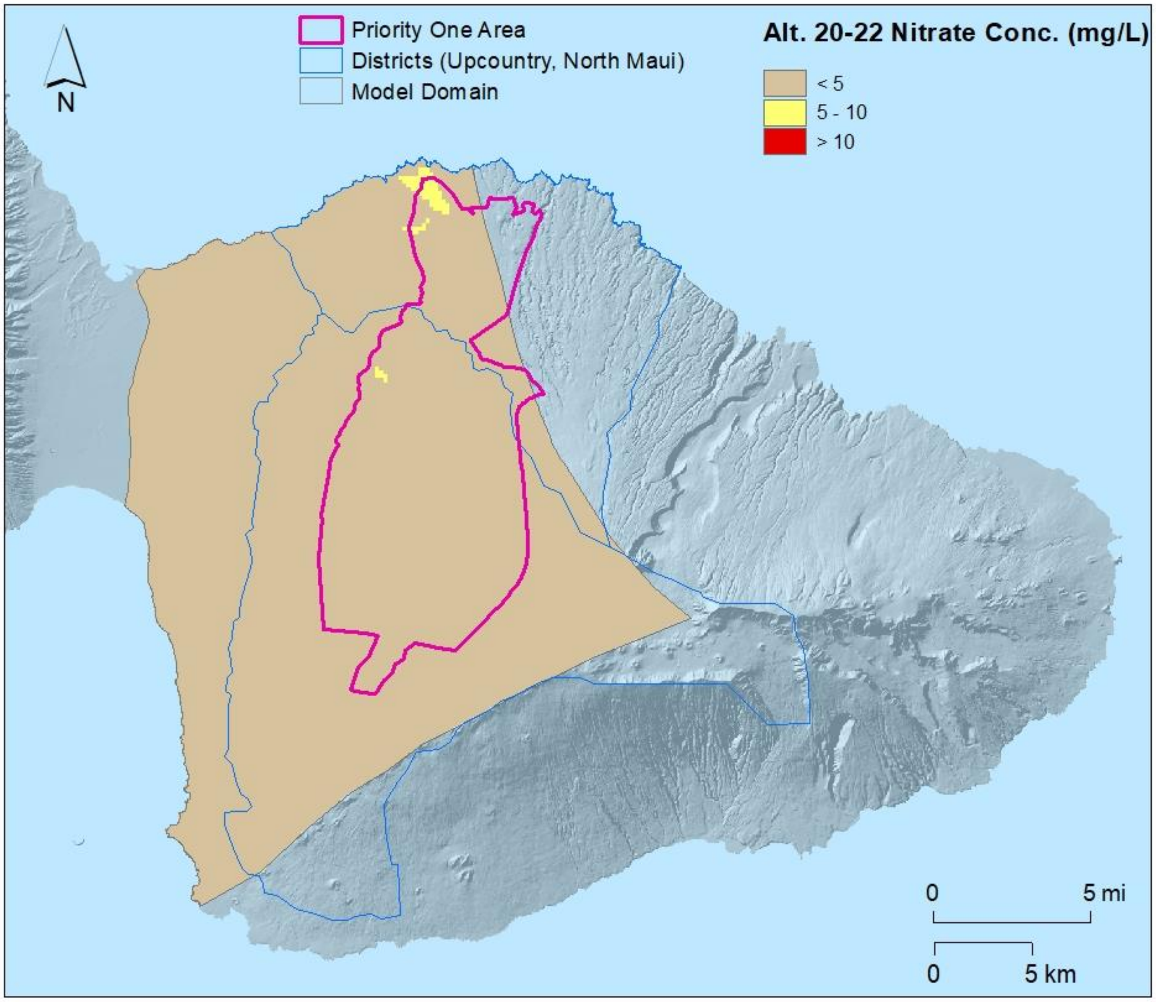

Figure AP5-20. Nitrate Concentrations of Alternatives 20-22: Sewer Makawao and Cesspool Upgrades to Septic Tank to Presby (cheapest option) Elsewhere, as possible

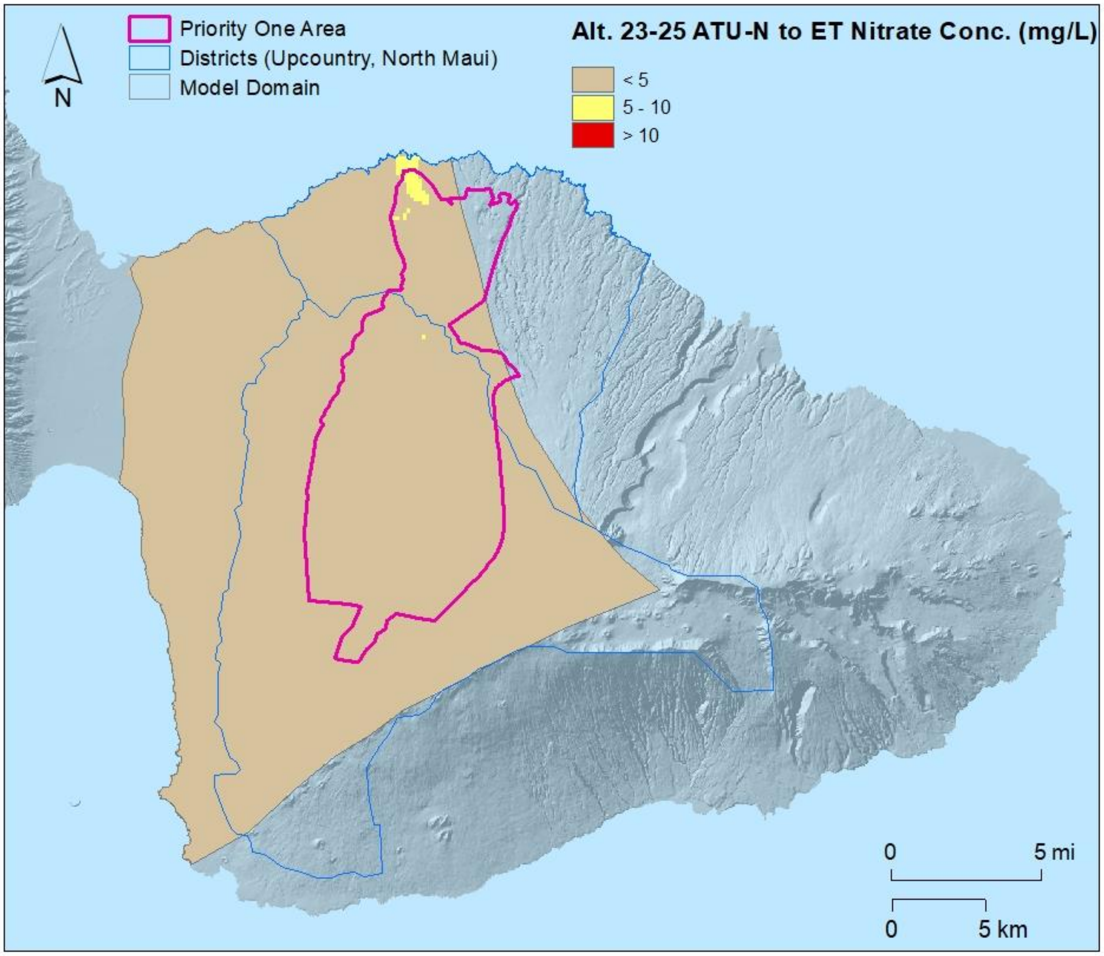

Figure AP5-21. Nitrate Concentrations of Alternatives 23A-25A: Sewer Pukalani and Cesspool Upgrades to Aerobic Treatment Unit-Nitrification to Evapotranspiration (smallest area >5 mg/L in alternatives 1-18) Elsewhere, as possible

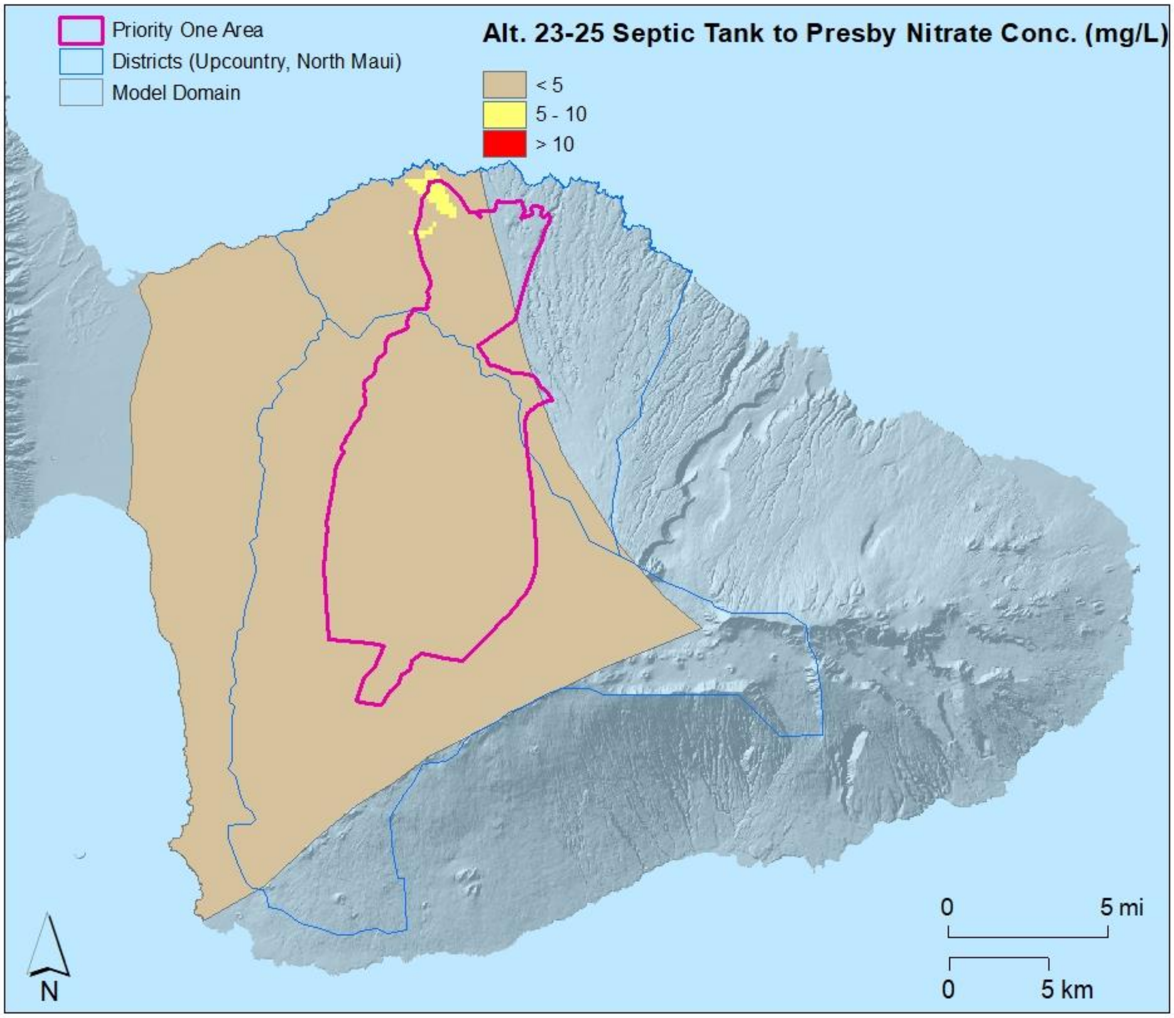

Figure AP5-22. Nitrate Concentrations of Alternatives 23B-25B: Sewer Pukalani and Cesspool Upgrades to Septic Tank to Presby (highest mass reduction in alternatives 1-18), as possible

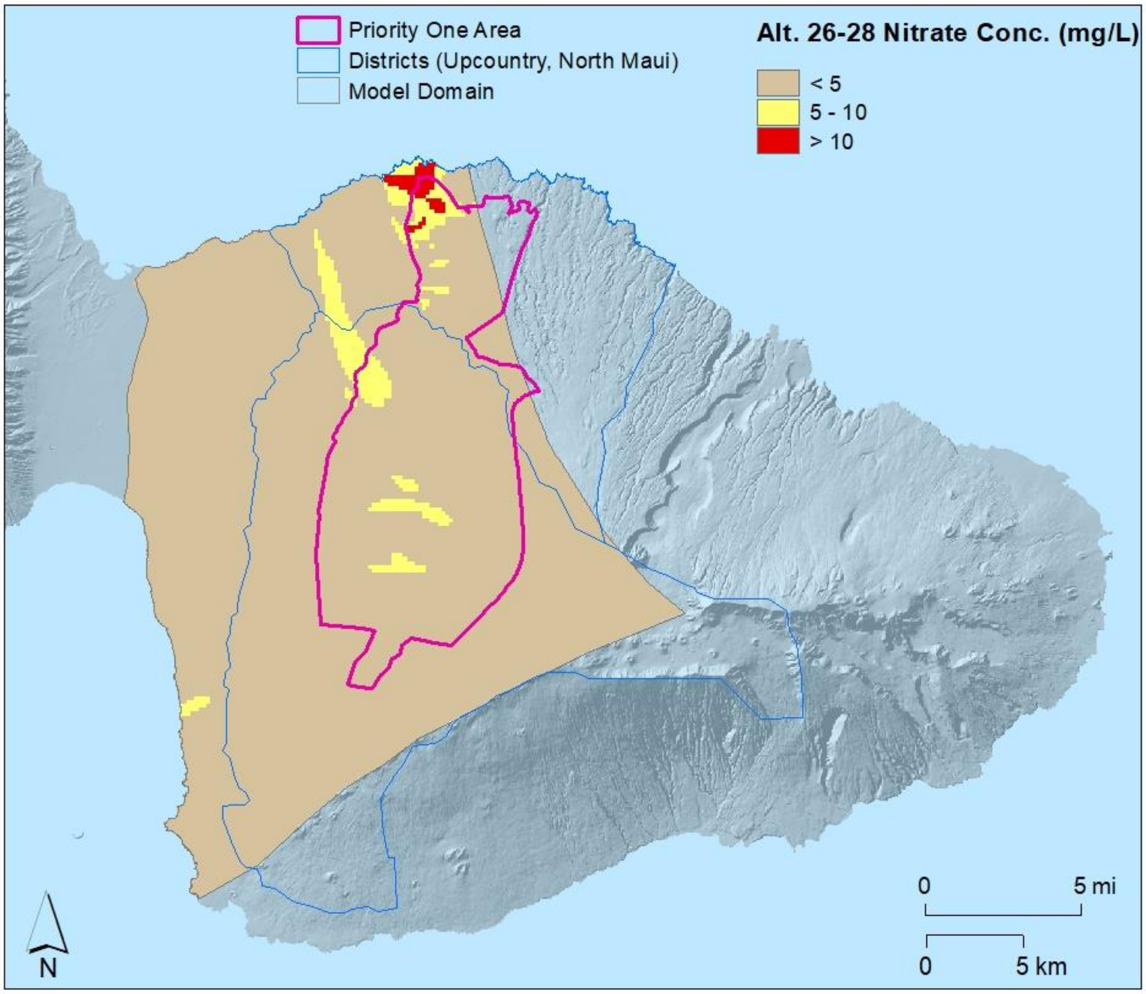

Figure AP5-23. Nitrate Concentrations of Alternatives 26-28: Sewer Makawao and No Cesspool Upgrades Elsewhere

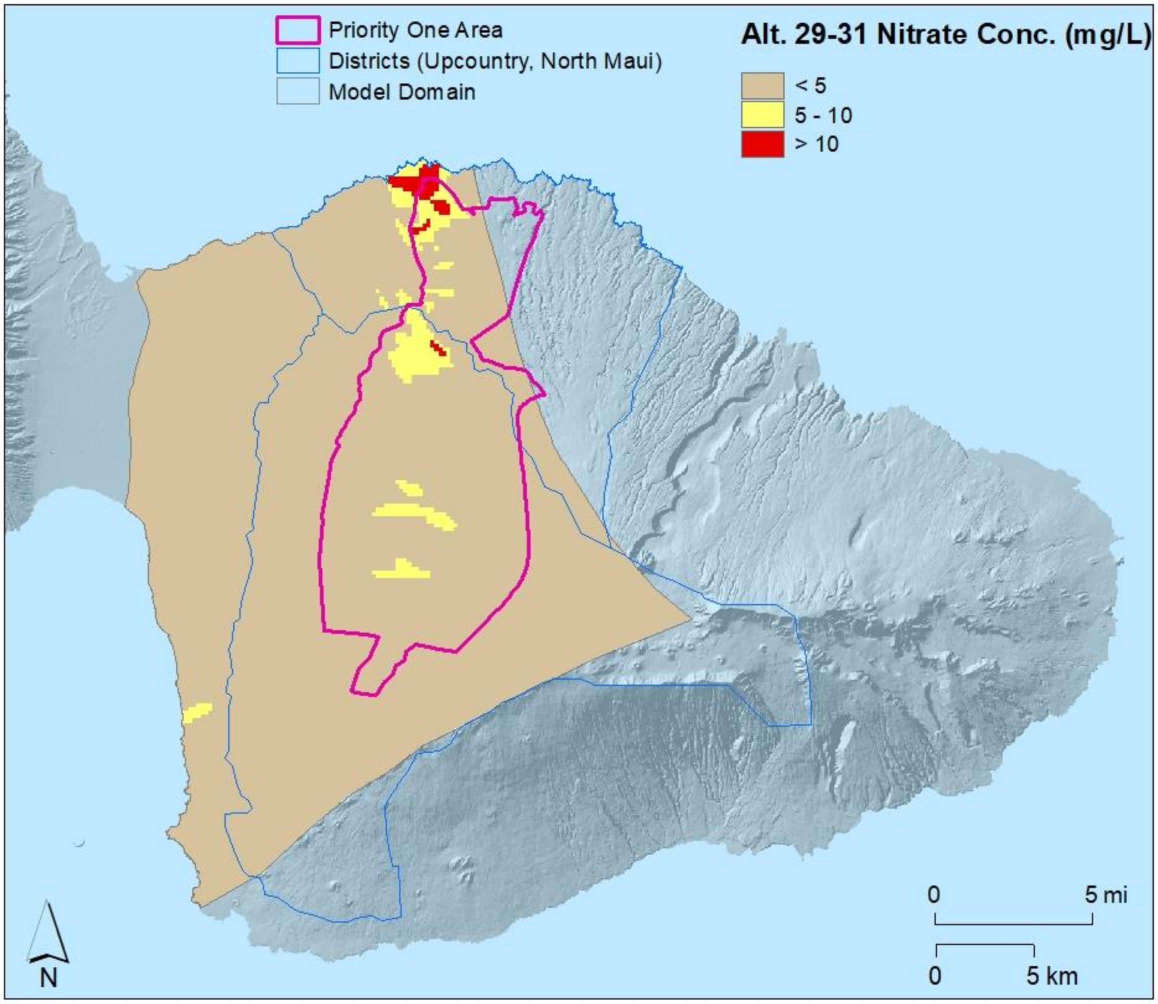

Figure AP5-24. Nitrate Concentrations of Alternatives 29-31: Sewer Pukalani and No Cesspool Upgrades Elsewhere

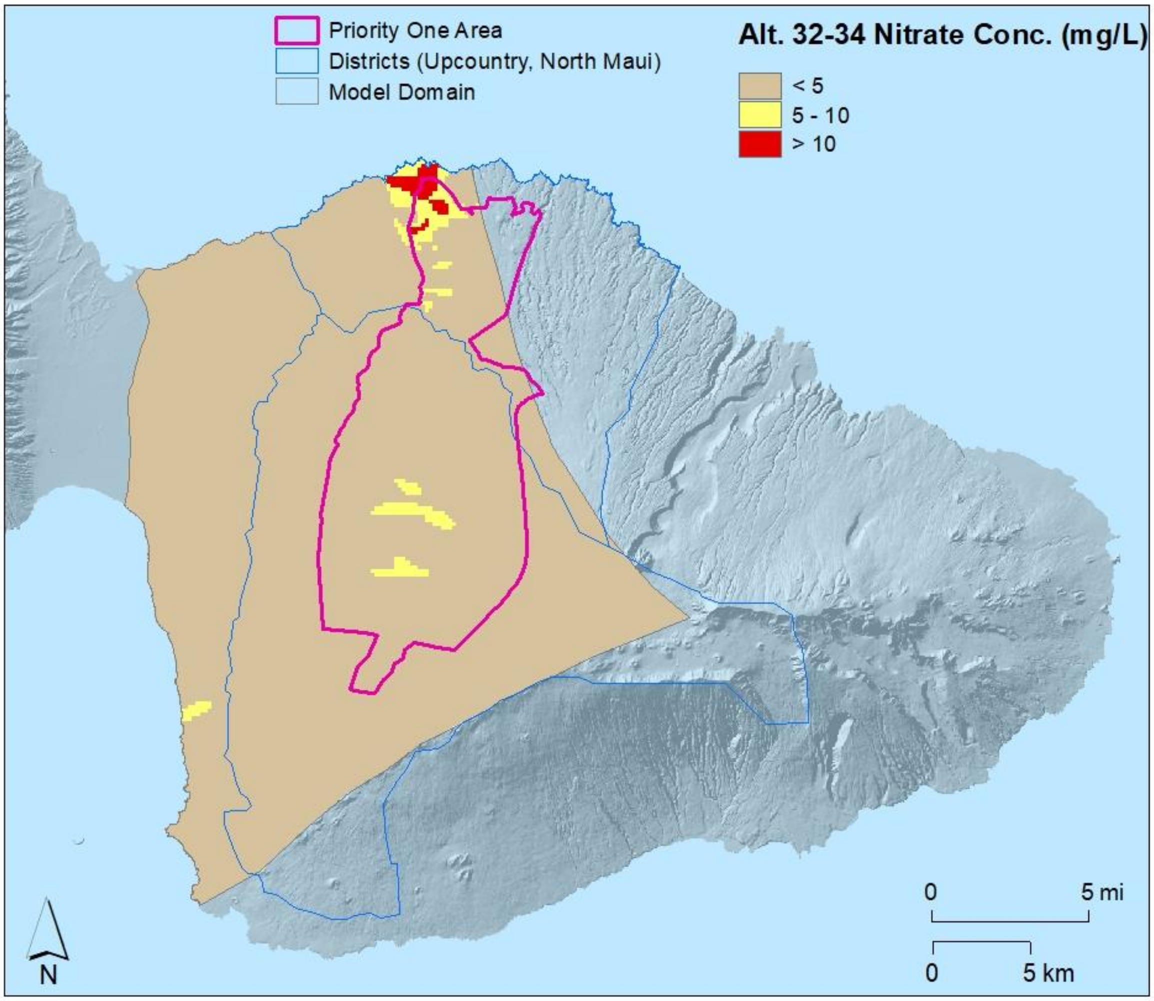

Figure AP5-25. Nitrate Concentrations of Alternatives 32-34: Sewer Makawao and Pukalani and No Cesspool Upgrades Elsewhere

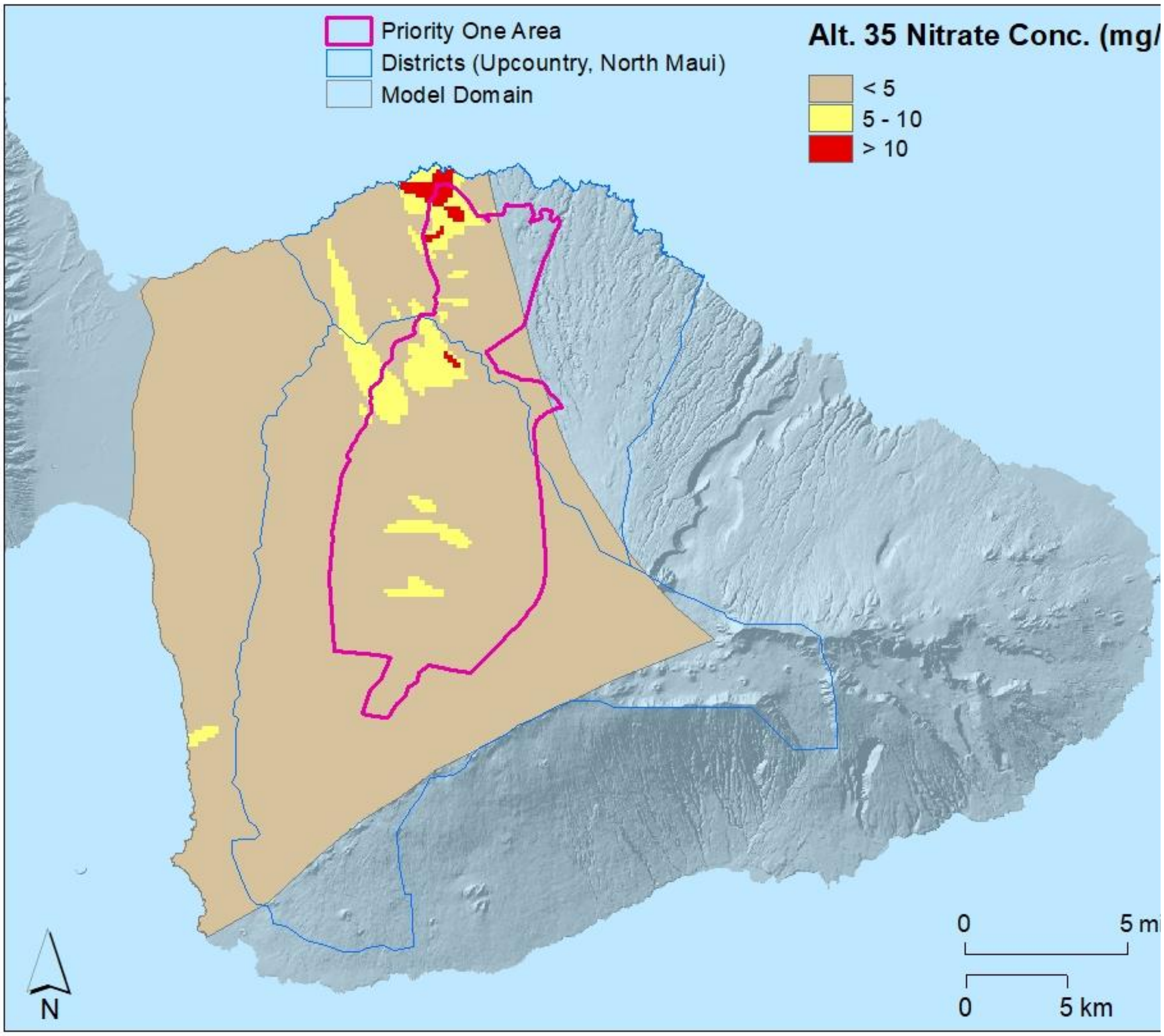

Figure AP5-26. Nitrate Concentrations of Alternative 35: Wellhead Treatment and No Cesspool Conversions

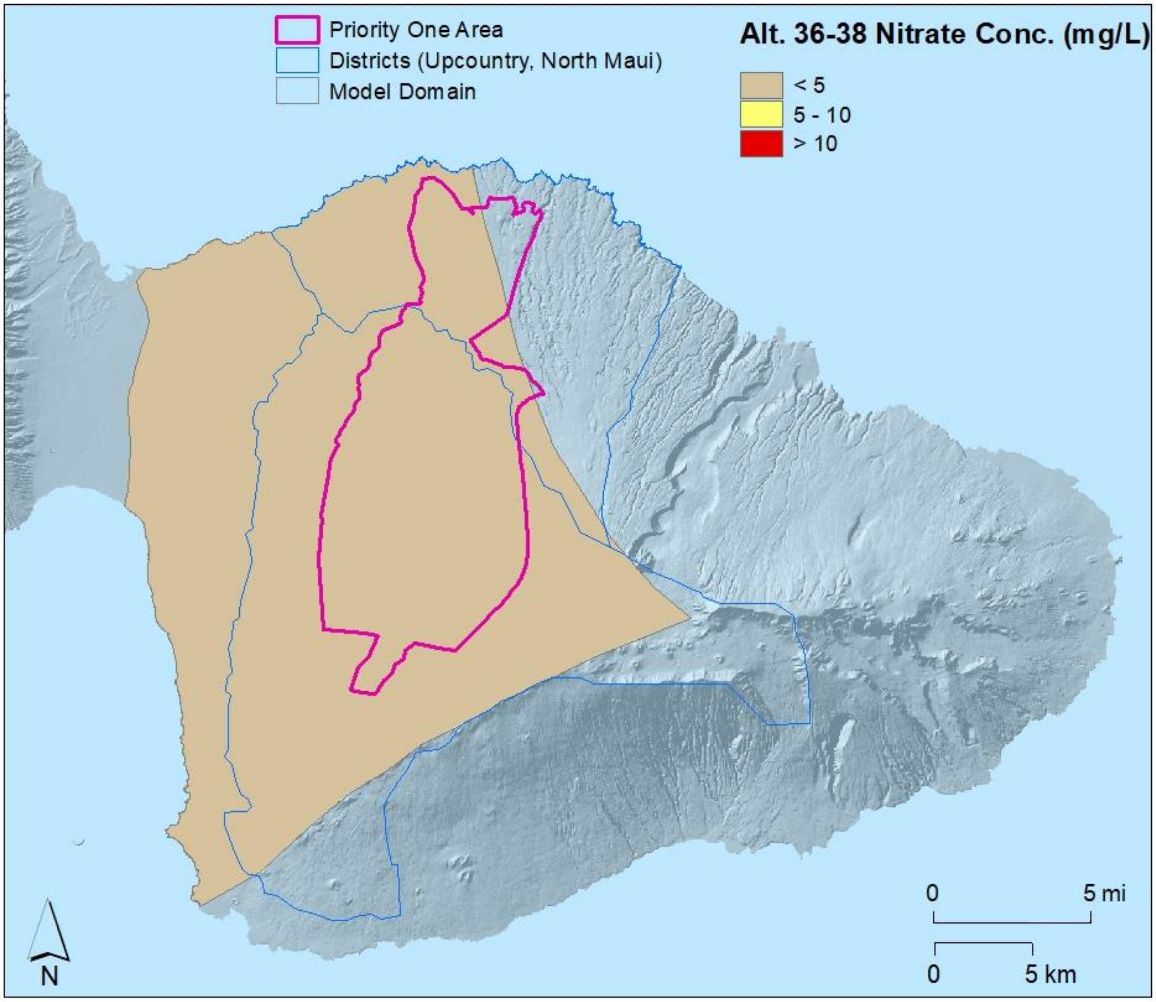

Figure AP5-27. Nitrate Concentrations of Alternatives 36-38: Compost Toilets with Graywater Reuse System